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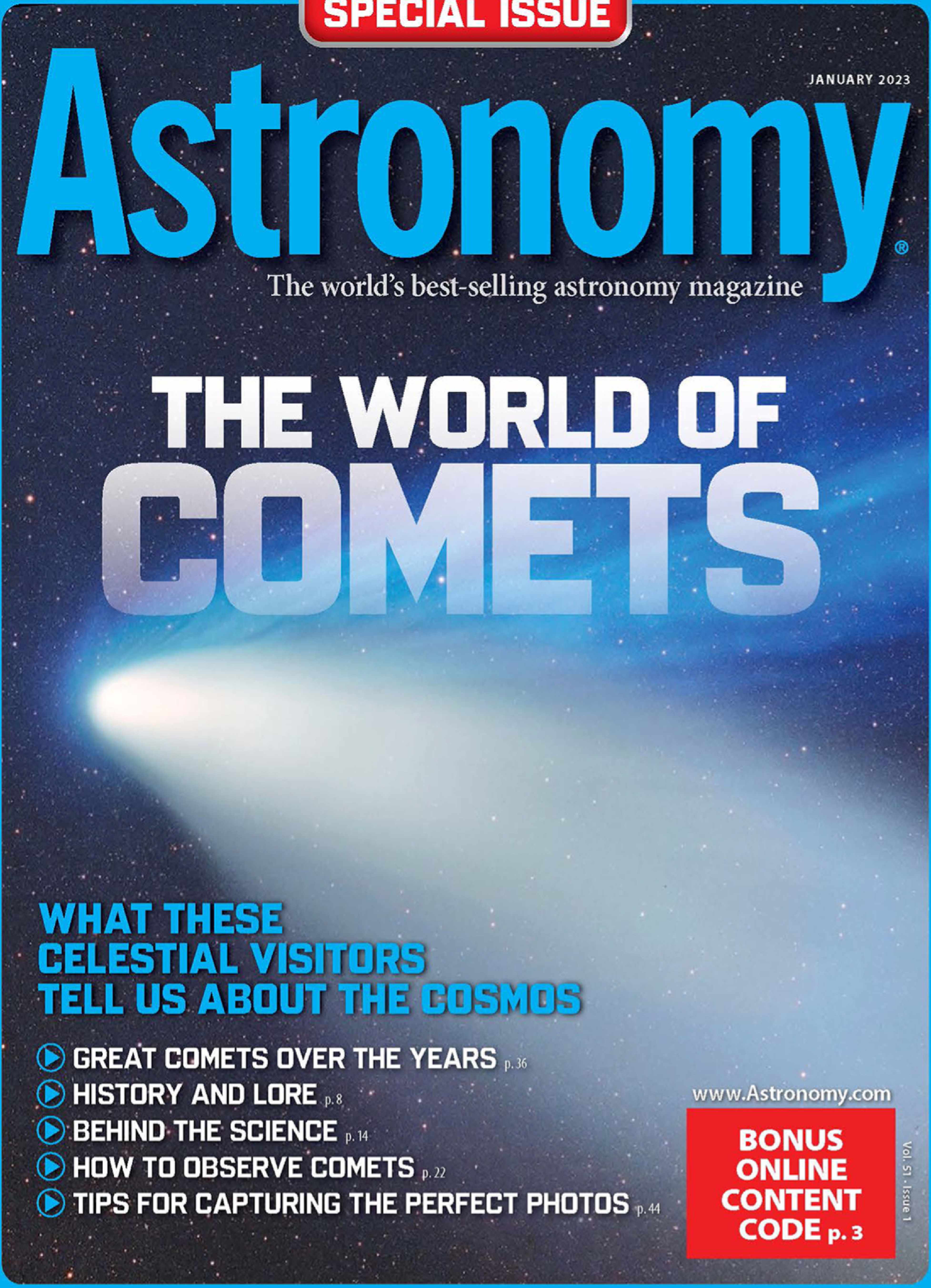

THE WORLD OF COMETS

WHAT THESE CELESTIAL VISITORS TELL US ABOUT THE COSMOS

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- HISTORY AND LORE p. 8
- BEHIND THE SCIENCE p. 14
- HOW TO OBSERVE COMETS p. 22
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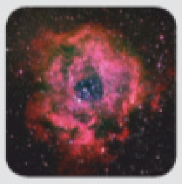
Go to **www.Astronomy.com** for info on the biggest news and observing events, stunning photos, informative videos, and more.



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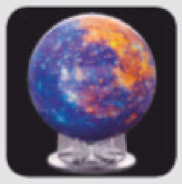

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ON THE COVER

The tails of Comet Hale-Bopp are a stunning sight in this image from March 27, 1997. GERALD RHEMANN

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FROM THE EDITOR

We celebrate 50 years!

On May 27, 1973, a young journalist named Stephen Walther, just 29 years old, filed papers of incorporation to establish a new company. AstroMedia Corp. of Milwaukee, Wisconsin, was on the precipice of publishing a new title devoted to the field of astronomy. Fittingly, the magazine adopted the title *Astronomy*, and the first issue appeared in August 1973. It featured a speckle interferogram of the star Betelgeuse in Orion on the cover, and five feature articles over a span of 48 pages.

It didn't take long for the little magazine to make its mark. Fueled by interest in astronomy and space coming out of the Apollo era, and aided by a few sky highlights like Comet West, the magazine grew as if on steroids. By 1981, *Astronomy* magazine had surpassed the long-established *Sky & Telescope* as the largest-circulation publication on the subject, a title it has never relinquished. Now, in our 50th anniversary year, we are still the largest-circulation title on astronomy, larger than our top U.S. competitor by a factor of two.

In July 2020, Comet NEOWISE was aglow in the evening sky and was a favorite target for astroimagers. It was one of the brightest recent comets for observers. DAMIAN PEACH

I have been on *Astronomy's* staff for 40 of the 50 years. Together, the editors and readers have had a magical ride, with many extraordinary events and discoveries along the way. Amazing eclipses, Halley's Comet, the confirmation of the Big Bang, the discovery of dark energy, the robotic exploration of our solar system, and countless other discoveries and experiences have given us a fantastic astronomical journey.

In this special year, our current editorial staff, one of the greatest groups I've ever had the privilege of working with, will bring you some extraordinary surprises. We begin with the current special issue: "everything you ever wanted to know about comets but were afraid to ask."

I hope you'll enjoy this ambitious package, and I look forward to another 50 great years for this amazing institution. Ya done good, Stephen.

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Yours truly,

David J. Eicher
Editor

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Capturing the MOON in high res
THE STAR that changed the cosmos

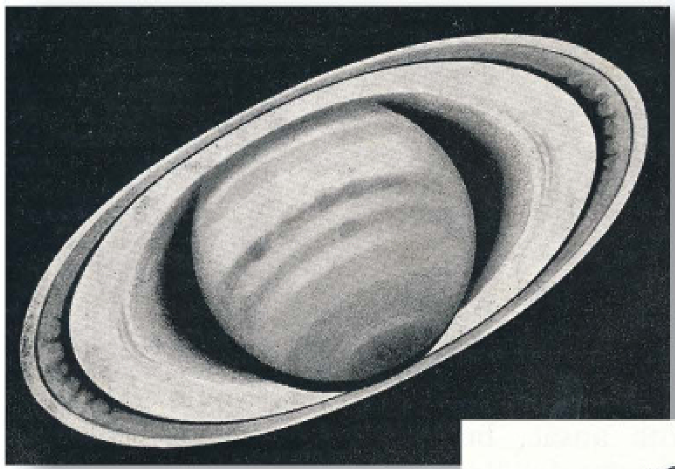
Stellar examples

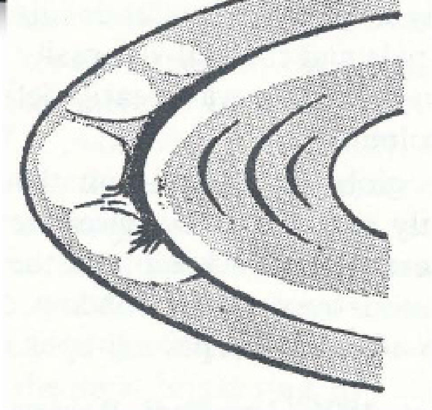
Compliments on the August 2022 issue, especially the excellent articles "Capturing the Moon in high res" by Leo Aerts and Klaus Brasch, and "The star that changed the cosmos" by Rod Pommier. Both stories describe exactly the adventures I seek when I roll my rig outside and pray for clear skies. **—Bruce de Graaf,** Northborough, MA

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to **letters@astronomy.com.** *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Erratum

In "Scopes for city-dwellers" from the August 2022 issue, the "Exit pupil" illustration on page 31 incorrectly showed the light leaving the eye lens as a parallel beam. In actuality, the image continues to draw to a focus as it enters the observer's eye. Scan the QR code above to see a corrected version of the diagram, accompanying the article on our website.





ABOVE: LUCIEN RUDUAX/*LE CIEL* BY ALPHONSE BERGET

RIGHT: E.M. ANTONIADI/*SPLENDOUR OF THE HEAVENS* ED. BY T.E.R. PHILLIPS AND W.H. STEVENSON

Spoke spotters

I always love reading anything about Saturn, so I very much enjoyed Stephen O'Meara's article, "Saturn's rings at their finest," in the September 2022 issue. I took special note of the sidebar on page 50, with some of the historic visual observations of the planet. I've always been impressed by the number of early observers who apparently perceived the "spokes" in the rings. See above for drawings by E.M. Antoniadi and Lucien Rudaux, from the late 1890s and 1923, respectively. **—Ron Miller,** South Boston, VA

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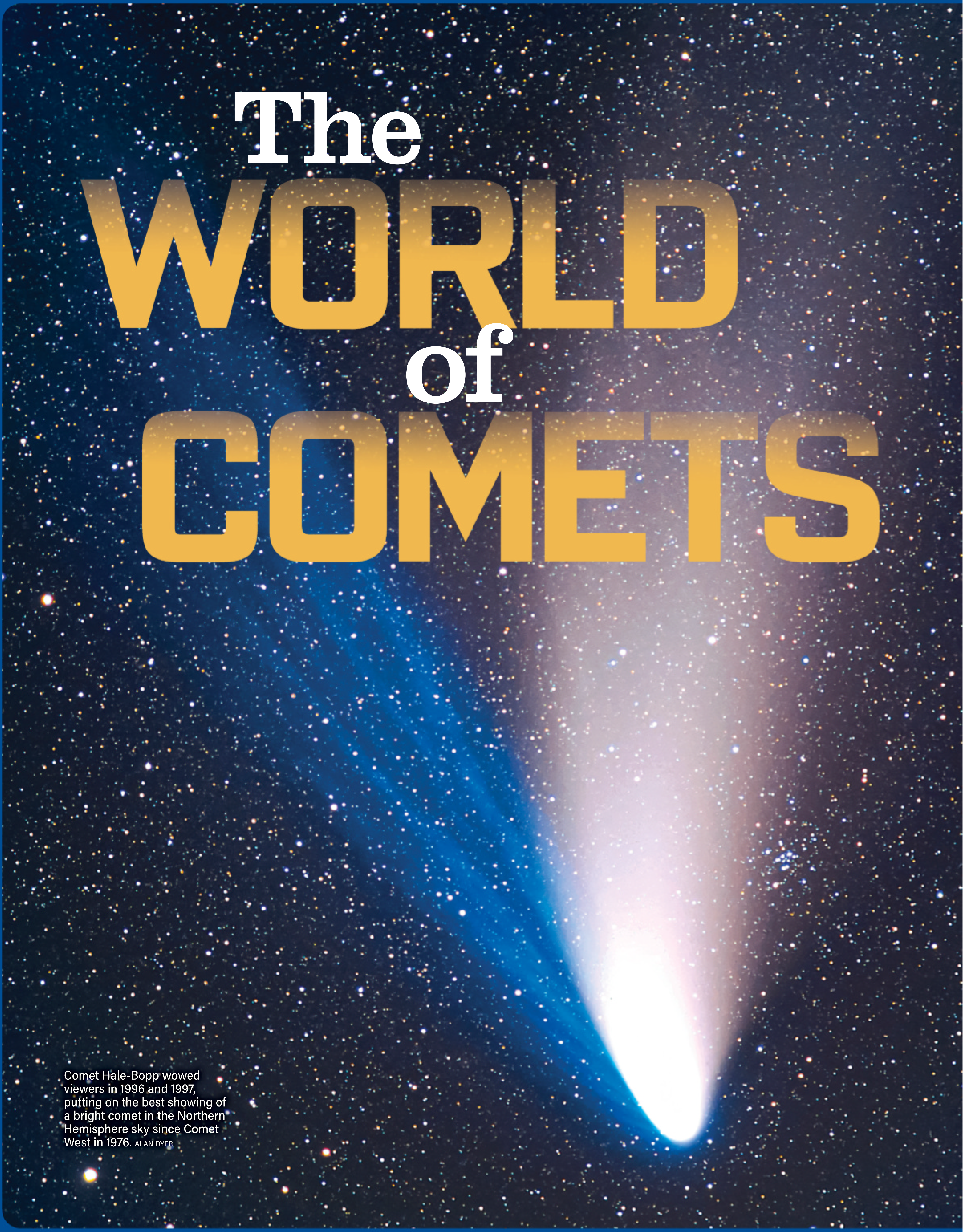
The WORLD of COMETS



Comet Hale-Bopp wowed viewers in 1996 and 1997, putting on the best showing of a bright comet in the Northern Hemisphere sky since Comet West in 1976. ALAN DYER

A noted comet discoverer reflects on comets and the meaning of life.

BY DAVID H. LEVY

THE WORLD OF COMETS

LITTLE MEANS MORE to me than comets. While in the sixth grade at Roslyn School in Montreal, I delivered the first of more than 2,500 lectures I've given in my life. The subject I chose for this first talk was comets, and it's amazing to me to compare what we knew about comets then with what we know now. For example, all those years ago, we knew of a few hundred comets; now we know of at least 4,000.

The most famous of all comets, Halley's Comet, last rounded the Sun on Feb. 9, 1986. Twenty-one years before that, on Dec. 17, 1965, I began searching telescopically for comets. On Nov. 13, 1984, I discovered my first. I'll never forget my view of a brand-new comet that no one else had seen, lying close to the open cluster NGC 6709 in Aquila. It struck me that the comet seemed to be wrapping its wavy tail around me and my telescope. That night, I felt a spiritual connection to the cosmos.

Since then, I have encountered more than 200 comets, 23 of which I discovered. The world of comets, I have learned, moves far more slowly than our fast-paced human world, with its news cycles changing every second. In their leisurely romps across the solar system, comets take their time as they teach us about the greater realm of space and time, of which we are a unique part.

Two comets are my particular favorites. My first discovery, Comet Levy-Rudenko, is one of them. The other is Comet Shoemaker-Levy 9, which Carolyn and Gene Shoemaker and I discovered on images we took on March 23, 1993. This comet did not look like much; when I arrived home after that week-long observing session at Palomar Mountain Observatory, I could see it only as a faint patch of fuzz that resembled the mark of a pencil erasure. But just as my first new comet had wrapped its tail around me, from March 1993 to July 16, 1994, Comet Shoemaker-Levy 9 wrapped itself around all three of us, taking us along its final orbit about Jupiter. This comet was not famous for what it was; it was famous for what it did. In its violent and deadly collision with Jupiter, it taught us how ancient collisions of comets with primordial Earth brought particles of carbon, hydrogen, oxygen, and nitrogen (together called CHON) to our world. From these tiny, elementary CHON particles eventually came amino acids and proteins, then RNA and ultimately DNA. As one scientist suggested, a comet's CHON particles represent the simple alphabet of life.

Something that enthralls me about comets is that they are not just comets. Early in the formation of the solar system, as they collided with each other and with slowly building protoplanetary bodies, they became part of the structure of planets themselves. Even now, as they cruise across the solar system, they release many specks of dust that continue to orbit the Sun as meteoroids. Occasionally, if we are lucky, we can see some hit Earth's upper atmosphere and vanish as falling stars. In 1995, one comet, called Schwassmann-Wachmann 3, broke apart dramatically. It brightened suddenly and released a huge amount of dust into space. On the night of May 30, 2022, Earth plowed through a small portion of this dust. Observers did not see thousands of shooting stars, but we did view a number of meteors that night, many caught by my camera.

Comets are like cats. They both have tails and they both do precisely what they want. We never can tell how the next comet will behave and what it will do until it happens. My first comet in 1984 passed so close to NGC 6709 that this field is forever engraved in my memory. Last month, another comet, named C/2017 K2 (PanSTARRS), happened also to travel in front of that lovely patch of sky. As I went outside and saw it, the years melted away and it was 1984 once again. On that same night, I also felt that I stood beside the English poet and Jesuit priest Gerard Manley Hopkins (1844–1889) as he replaced telescope with pen and wrote:

"I am like a slip of comet,
Scarce worth discovery, in some corner seen
Bridging the slender difference of two stars . . .
But when she sights the Sun she grows and sizes
And spins her skirts out, while her central star
Shakes its cocooning mists; and so she comes
To fields of light; millions of travelling rays
Pierce her; she hangs upon the flame-cased sun
And sucks the light as full as Gideon's fleece
But then, her tether calls her; she fades off,
And as she dwindles sheds her smock of gold."

Comets are not just for astronomers to relish through their advanced instruments. Comets are for all of us to enjoy through telescopes, through binoculars, and simply just with our eyes. With their tails they brighten our lives and with their magic they enchant our souls.

David H. Levy *is well known as a comet discoverer, having found 23 comets. Among them is his codiscovery of Comet Shoemaker-Levy 9, which impacted Jupiter in 1994.*

Unlocking the MYSTERY

THE WORLD OF COMETS

Today, comets are a sight to behold, but for most of history they were seen as harbingers of doom.

BY RAYMOND SHUBINSKI

"OF ALL THE HEAVENLY BODIES, comets are assuredly those whose appearance strikes most forcibly the attention of mortals," wrote French astronomer Camille Flammarion in his book *Popular Astronomy* (1894). And, for as long as humans have looked toward the sky, it's been true. Comets have both terrified and amazed us.

This was never more apparent in modernity than in 1910. Comet 1P/Halley, better known as Halley's Comet, had last been visible in 1836 and would grace the heavens again that spring. The comet's return was highly anticipated, so imagine everyone's surprise when a brilliant comet unexpectedly appeared months earlier.

# of COMETS

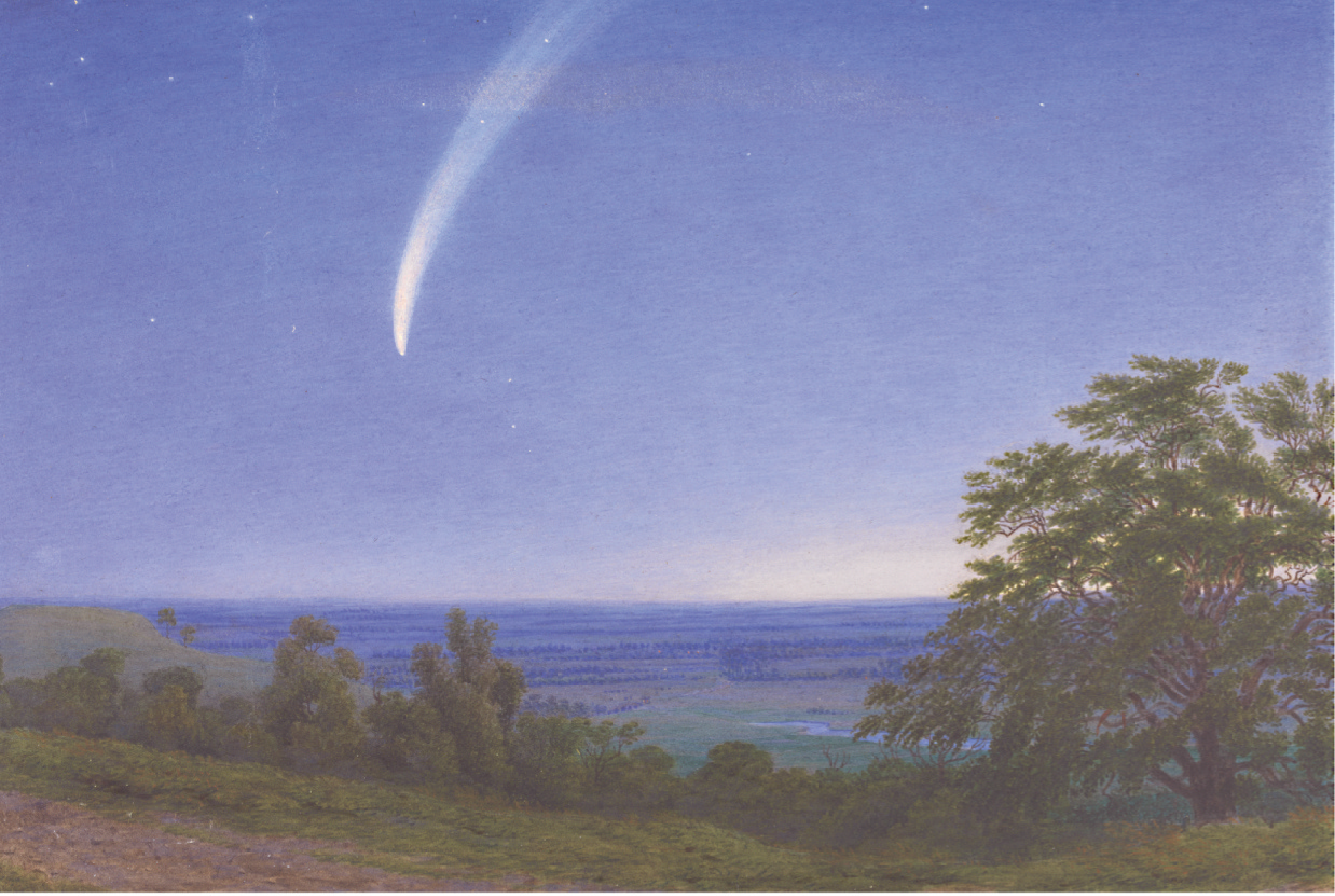
ABOVE: When Halley's Comet returned to Earth's skies in 1910, it was once again viewed with superstition and dread. PROFESSOR EDWARD EMERSON BARNARD AT YERKES OBSERVATORY, IN WILLIAMS BAY, WISCONSIN

INSET: It has been speculated that the Christmas star in Giotto di Bondone's *The Adoration of the Magi* (1320) was inspired by his experience of Halley's Comet in 1301. JOHN STEWART KENNEDY FUND, 1911

The object that would become known as both the Great January Comet of 1910 and the Daylight Comet was first seen Jan. 12 in the Southern Hemisphere. It's unclear who precisely discovered it, but some newspapers at the time pointed to observers in South Africa. On Jan. 17, the comet reached perihelion — its closest approach to the Sun — and could be seen in broad daylight, outshining Venus at its brightest. As it moved away from the Sun, it became visible in the Northern Hemisphere shortly after sunset. By February, a 50°-long tail swept away from the comet's head.

Confusion caused many to mistake the apparition for the more famous Halley's Comet, which was seeing increased media attention after scientists detected the presence of cyanogen in its tail. With Earth predicted to pass through it on May 18/19, Flammarion warned in *The San Francisco Call* Feb. 8, 1910, that the gas could "impregnate the atmosphere and possibly snuff out all life on the planet." The misinformation ran counter to the scientific consensus that any danger would be eliminated when the cyanogen decomposed in the upper atmosphere.

By early April 1910, when Halley's Comet became visible once more, a full-blown media extravaganza surrounded its return. At this point, some thought Halley would collide with Earth, despite astronomers' assurances to the contrary. As panic ensued, charlatans hawked comet pills as



William Turner's *Donati's Comet* was inspired by the comet appearing over Oxford Oct. 5, 1858. YALE CENTER FOR BRITISH ART, PAUL MELLON COLLECTION

protection against the deadly gas, while others flocked to churches, bought gas masks, and tried to seal up their homes to keep out the cyanogen.

Despite the efforts of astronomers and scientists, humanity's latent fear of these celestial visitors had resurfaced.

Ruining perfection

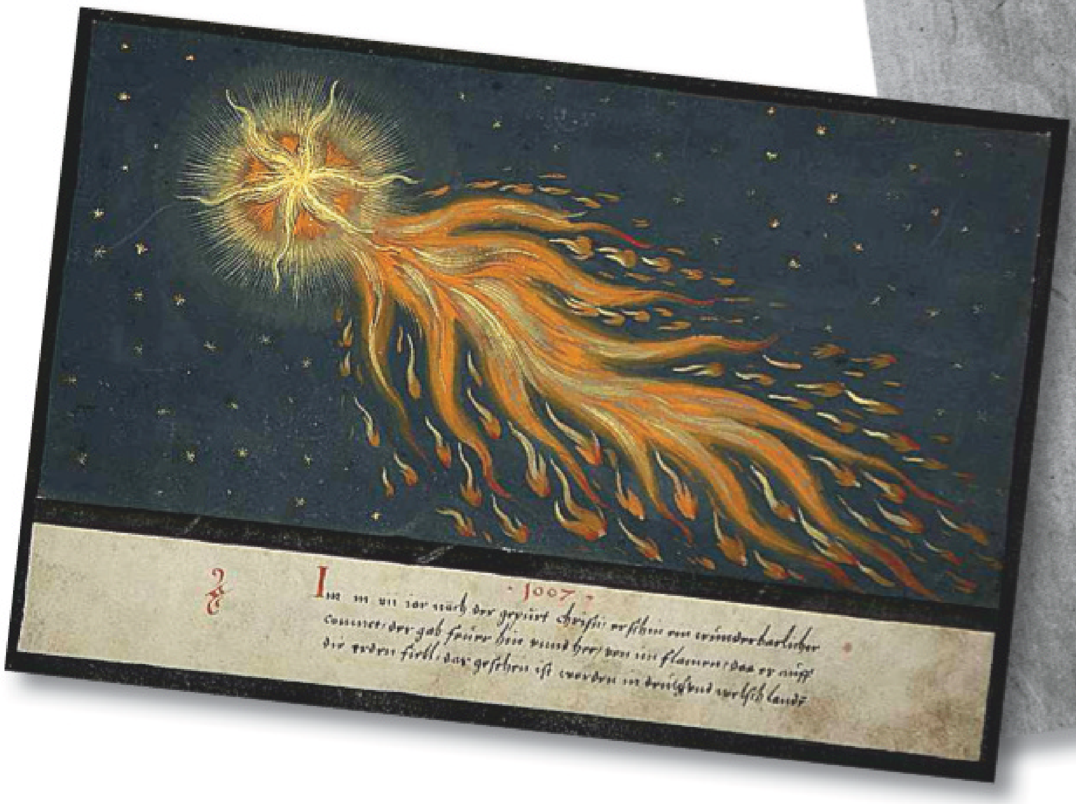
Many ancient cultures saw comets as harbingers of doom and disaster. The predictable motions of the planets, the Sun, and the Moon, as well as the seasonally changing constellations, were reassuring in a chaotic world. A comet's sudden appearance shattered this order.

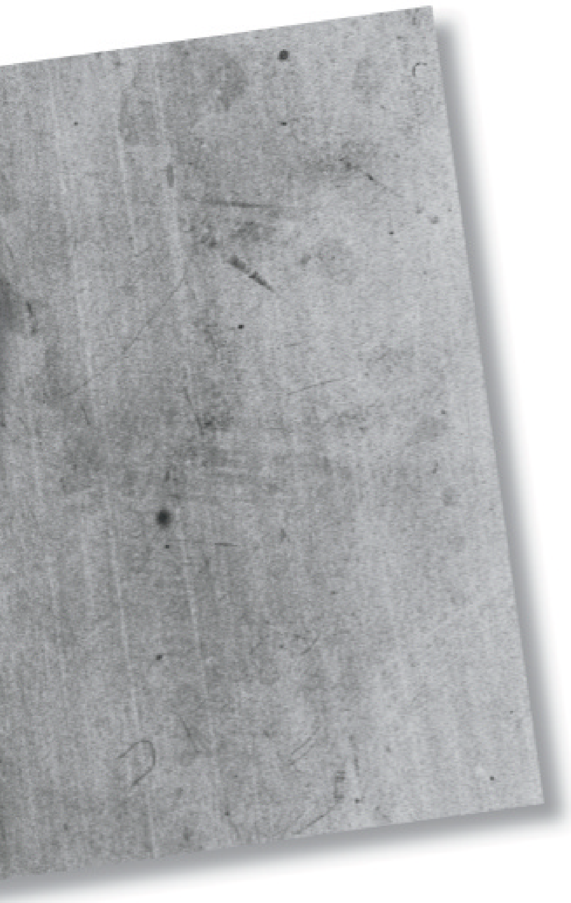
The predictable motions of the skies were reassuring in a chaotic world. A comet's sudden appearance shattered this order.

Aristotle described Earth and the sky as fundamentally different spheres. The terrestrial sphere was ever-changing and corruptible. Beyond lay the realm of perfection where the Sun, the Moon, and planets rotated on incorruptible crystalline spheres. It seemed inconceivable that a random disruption could pass through this realm of perfection. So, to explain this corruption, Aristotle suggested that comets were vapors that rose from Earth and ignited in the upper atmosphere. Astronomers ultimately rejected Aristotle's explanation, but his views held sway in Western philosophy for more than 1,500 years.

Westerners weren't alone in these beliefs, either. Chinese astronomers called comets "bushy stars" (孛星; *bèi xīng*) if they had no tail, or "broom stars" (彗星; *huìxīng*) if they had one. Ancient Chinese records of comet observations were the most extensive and accurate of both the ancient and medieval periods. Yet they too saw these visitors as disastrous omens.

Eventually, a Danish nobleman would defy superstition and overthrow Aristotle's lingering ideas. And this end was heralded by a bang. In November 1572, a "new" star — today we know that star was a supernova — appeared in the constellation Cassiopeia. The young Tycho Brahe was one of the first to make detailed measurements of this event. Brahe could not detect any parallax for the star, which would have been measurable if the object was atmospheric. Brahe's conclusion was simple: The new star was in heaven itself, within the so-called eighth sphere, the realm of immutability. To those who doubted his





LEFT: Early European literature is filled with illustrations showing comets as vapors and spirits, burning swords, dragons, and balls of fire suspended in the sky. AUGSBURG BOOK OF MIRACLES/WIKIMEDIA COMMONS

RIGHT: Although the first photo of a comet has been lost to time, the second is not. This plate, taken by George Phillips Bond Sept. 28, 1858, shows a fuzzy smudge that is Comet Donati. MODERN ENLARGED PHOTOGRAPHIC PRINT OF GEORGE PHILLIPS BOND'S PLATE III, SEPTEMBER 28, 1858, DONATI'S COMET, HARVARD COLLEGE OBSERVATORY, PHOTOGRAPHIC GLASS PLATE COLLECTION

findings, he said, "*O coecos coeli spectatores*," which roughly translates to "O blind spectators of heaven."

Five years later, Brahe tested his theory on a newly visible comet. He was now equipped with a private observatory filled with instruments of his own design. Telescopes were still decades away, but he could measure the comet's course and position with great accuracy. As with the new star of 1572, he found no parallax, placing the comet among the realm of planets. His findings were not accepted by many of his contemporaries, including Johannes Kepler and later Galileo Galilei. Even Brahe himself could not completely shake off the bonds of astrology, making predictions about the comet's influence on Earth. Nevertheless, Aristotle's crystalline spheres were soon abandoned.

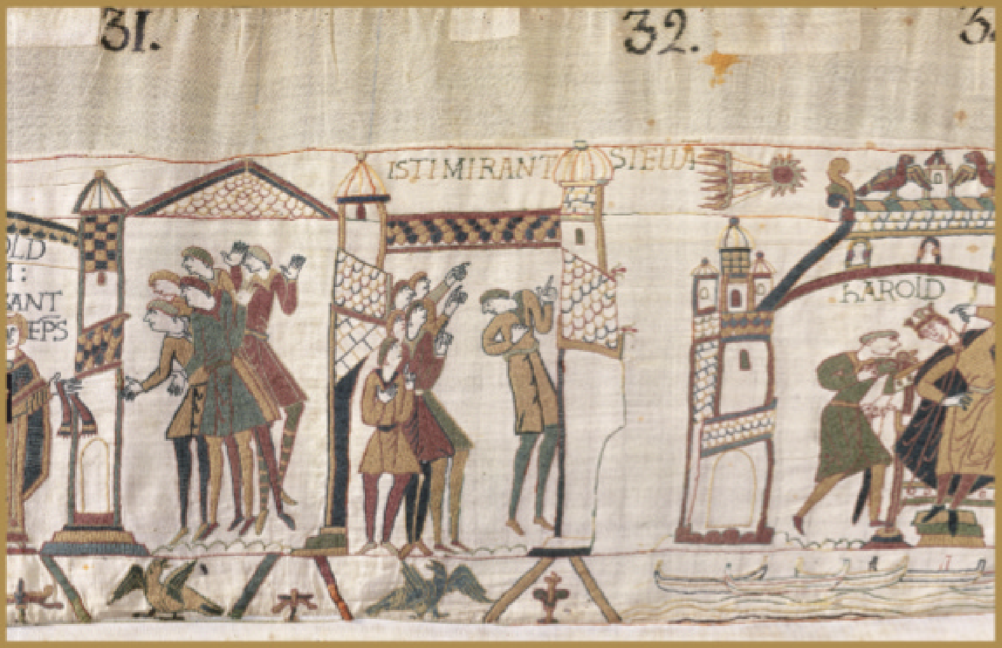
By the mid-17th century, the Age of Enlightenment was in full bloom. Brahe's observational work on comets and Kepler's laws of planetary motion provided novel tools for a new generation of astronomers. Among them was a young man named Edmond Halley.

The most famous comet

Halley's interest in the cosmos began early in life. When he went to study at the Queen's College of the University of Oxford, he took a large telescope with him and, as an undergraduate, wrote a handful of papers. In 1676, at the age of 20, he left school and sailed for the island of St. Helena in the Southern Hemisphere. He spent a year mapping the southern sky before publishing his star catalog in 1678. Two years later, he embarked on a grand tour of Europe, visiting observatories and meeting with scientists.

While on his tour, Halley saw the Great Comet of 1680 from Paris. It was discovered by the German astronomer Gottfried Kirch and was the first comet

SIGNS AND OMENS



Sightings of Halley's Comet go back to 240 B.C. However, the first illustration of the comet wasn't made until A.D. 1066 in the Bayeux Tapestry. BAYEUX TAPESTRY 11TH CENTURY ©BAYEUX MUSEUM

COMETS WERE VIEWED as disruptors of a perfect cosmic routine. As Carl Sagan said, a comet's appearance was "assured of some tragedy for which it can be held accountable." Halley's Comet made an easy scapegoat over the centuries, each time it returned to the sky.

1066 The cosmic visitor was viewed as a bad omen for the Anglo-Saxons' kingdom, then ruled by Harold II. A month after William of Normandy invaded, the king died at the Battle of Hastings. The Bayeux Tapestry, which recorded the conquest, depicts the first-known illustration of Halley's Comet.

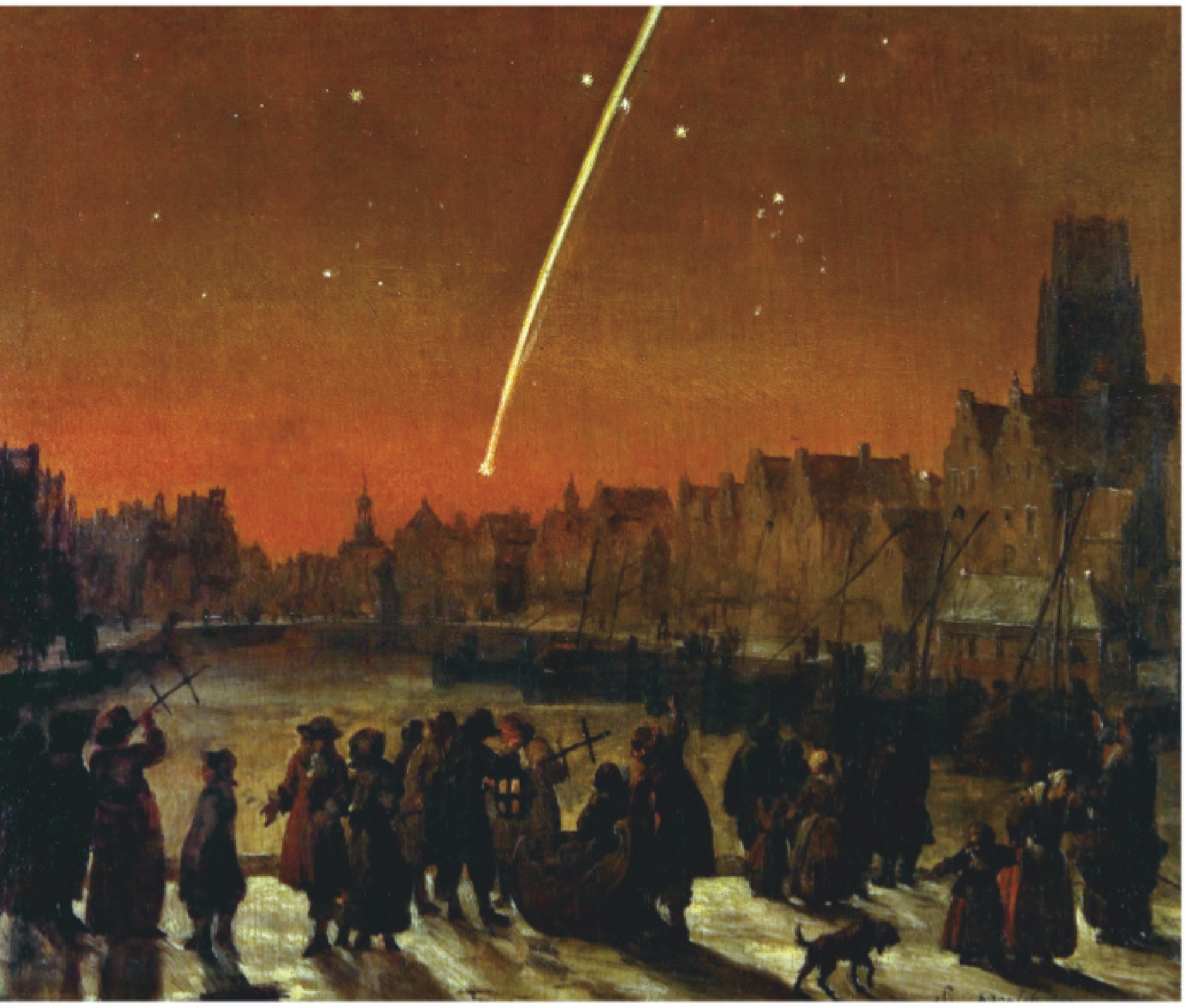
1301 Halley's Comet once again graced the heavens. A few years later, Italian artist Giotto di Bondone painted *The Adoration of the Magi.* Art historians believe this was Comet Halley as Giotto remembered it — a rare example of Halley's comet being viewed as a blessing.

1456 The last vestige of the Roman Empire vanished when the Ottomans captured Constantinople in 1453. Europe was awaiting a full-scale invasion from the Turkish army when Comet Halley reappeared in 1456, fueling panic and despair. By some reports, Pope Calixtus III ordered church bells to be rung every day at noon for intercession against the comet's influence. *—R.S.*

ever found with a telescope. Halley watched the comet brighten into daylight visibility and later develop a tail that stretched some 70°. The Italian astronomer Giovanni Domenico Cassini, who was working at the Paris Observatory, told Halley that he thought comets like this orbited the Sun with predictable accuracy.

In 1682, yet another comet appeared in the sky. Halley and many others, including Isaac Newton, observed this comet closely. Halley kept detailed positional records. At the time, there was still considerable debate about the nature of cometary motion and orbits, but astronomers didn't have to wait long for a breakthrough. Just two years later, after prodding from Halley, Isaac Newton began work on the *Philosophiae Naturalis Principia Mathematica*, in which he dedicated considerable discussion to comets.

When Halley worked on cometary orbits in 1685, it was with the *Principia* at his side. He noted the comets of 1531, 1607, and 1682 had similar orbits. He boldly postulated that they were one and the same, and predicted this comet would reappear at the end of December 1758 — which it did. Unfortunately, Halley did not live to see its return, as he passed away in 1742. But his legacy was cemented at a meeting of the Paris Academy of Sciences in 1759, when astronomer Nicolas-Louis de Lacaille first referred to the body as the name we know it by today: Halley's Comet.



The Great Comet of 1680 was the muse for Lieve Verschuier's *Tail Star (Comet) over Rotterdam* (1680). MUSEUM ROTTERDAM (PURCHASE WITH THE SUPPORT OF THE REMBRANDT ASSOCIATION)

Unraveling the truth

While some have clearly risen to ready recognition, these otherworldly bodies remained a mystery well into the 19th and 20th century. A bumper crop of comets from 1811 to 1882 allowed astronomers to utilize an arsenal of new equipment and technology, with a clue to cometary structure coming in 1826, when astronomers observed Comet Biela (called Gambart's Comet) with improved telescopes. Calculations showed it was a short-period comet returning about every seven years. But when it was seen again in 1846, the nucleus had split into two separate objects! This gave the first indication that comets were not solid, but instead fragile objects that could be torn apart.

And as telescope equipment improved, so did photography. In 1840, John W. Draper, an American scientist, captured the first clear image of the Moon. (Though some sources point to French

COMETS GALORE

THE 19TH CENTURY proved a fruitful time for comet hunters, with spectacular shows occurring every few decades.

1811 The Great Comet was visible to the unaided eye for nine months. This was a record that would only be broken by Comet Hale-Bopp when it graced the skies in 1996 and 1997.

1843 In March, a sungrazing comet blazed in the night sky. Also known as the Great March Comet, it inspired wonder worldwide. It was described by the British astronomer Charles Piazzi Smyth as appearing to the naked eye to have "a double tail about 25° in length."

1858 Giovanni Battista Donati first spotted his namesake comet in early June. It was well placed in the sky for Northern Hemisphere observers. By August, it was visible without optical aid and sported a bright, curving tail.

1882 The Great September Comet dazzled viewers in the Southern Hemisphere. Yet another sungrazing comet, it was first seen Sept. 1, becoming a daylight comet by midmonth. At the comet's Sept. 17 perihelion pass, it may have reached between magnitude –15 to –20, making it up to a thousand times brighter than the Full Moon! *—R.S.*

The Great Comet of 1882, as photographed by amateur photographer William Simpson in Aberdeen, South Africa. SAAO; SIMPSON

While observing and photographing comets with Edward Emerson at Yerkes Observatory, astronomer Daniel Morehouse caught this visitor near Cassiopeia. His observations led him to speculate that comet tails were affected by solar weather. "COMET 1908C (MOREHOUSE)," *GALLERY*, ACCESSED AUGUST 16, 2022, HTTP://GALLERY.LIBRARY.VANDERBILT.EDU/ITEMS/SHOW/984

photographer Louis Daguerre as the first to capture Luna, his success is contested, and the fire that destroyed his lab in 1839 makes it impossible to prove.) French physicists Léon Foucault and Louis Fizeau photographed the Sun in amazing detail in 1845 and Draper, along with American astronomer William C. Bond, imaged the star Vega in 1850. All of the images were taken on a daguerreotype. Cometary scientists tried to capture their targets as well, but hazy comas and diaphanous tails proved a challenge. They persevered, however, and finally William Usherwood photographed Comet Donati in 1858. Unfortunately, the image has not survived.

And astronomers didn't have to wait long for another powerful new tool: the astronomical spectroscope. This instrument could reveal the elements present in stars, nebulae, galaxies, and comets. Giovanni Battista Donati used a spectroscope in 1864 to study Comet Tempel (C/1864 N1). His work showed emission from diatomic carbon in the comet's spectrum, which ultimately revealed its composition. As spectroscopy improved, astronomers found that the coma of a comet, which surrounds the hidden nucleus, contains vast amounts of dust that is pushed away by the radiant pressure of sunlight. Cometary tails are made of this dust, which reflects sunlight, as well as gases that glow from ionization.

Yet what lay within the dusty veil of the coma remained a mystery. It wasn't until 1950 that Harvard University astronomer Fred Whipple proposed the "dirty snowball" model for a comet's nucleus. He suggested that the core of a comet was made of loosely packed ice — a so-called icy conglomerate — protected by a thick layer of dust, dirt, and rock. This model provided an explanation for the dust and gas in a comet's tails, as well as explaining why the predicted return of a comet could be off by a few days. And, in 1986, when the European Space Agency's Giotto mission to Halley's Comet returned images of the comet's nucleus, they showed Whipple's model was fundamentally correct.

Around the same time that Whipple proposed his model of the comet's nucleus, the Dutch astronomer Jan Oort was carefully analyzing the orbits of long-period comets. He found that many comets seem to originate about 20,000 astronomical units (AU; where 1 AU is the average Earth-Sun distance) from our star. This spherical region has become known as the Oort Cloud, and it expanded the bounds of our solar system.

With more than 3,500 comets recognized by NASA today, we now comprehend comets in more detail than we ever thought possible. A better understanding of these comets has relieved some of the fear and superstition that accompanies these celestial visitors as they pass through our night sky. But by no means have they lost their wonder.

Raymond Shubinski *is a long-time contributing editor to* Astronomy *magazine. He has been observing comets since he was a kid and is eagerly waiting for the next bright comet to appear.*

These mysterious iceballs are key to understanding our solar system's history.

BY WALTER HARRIS

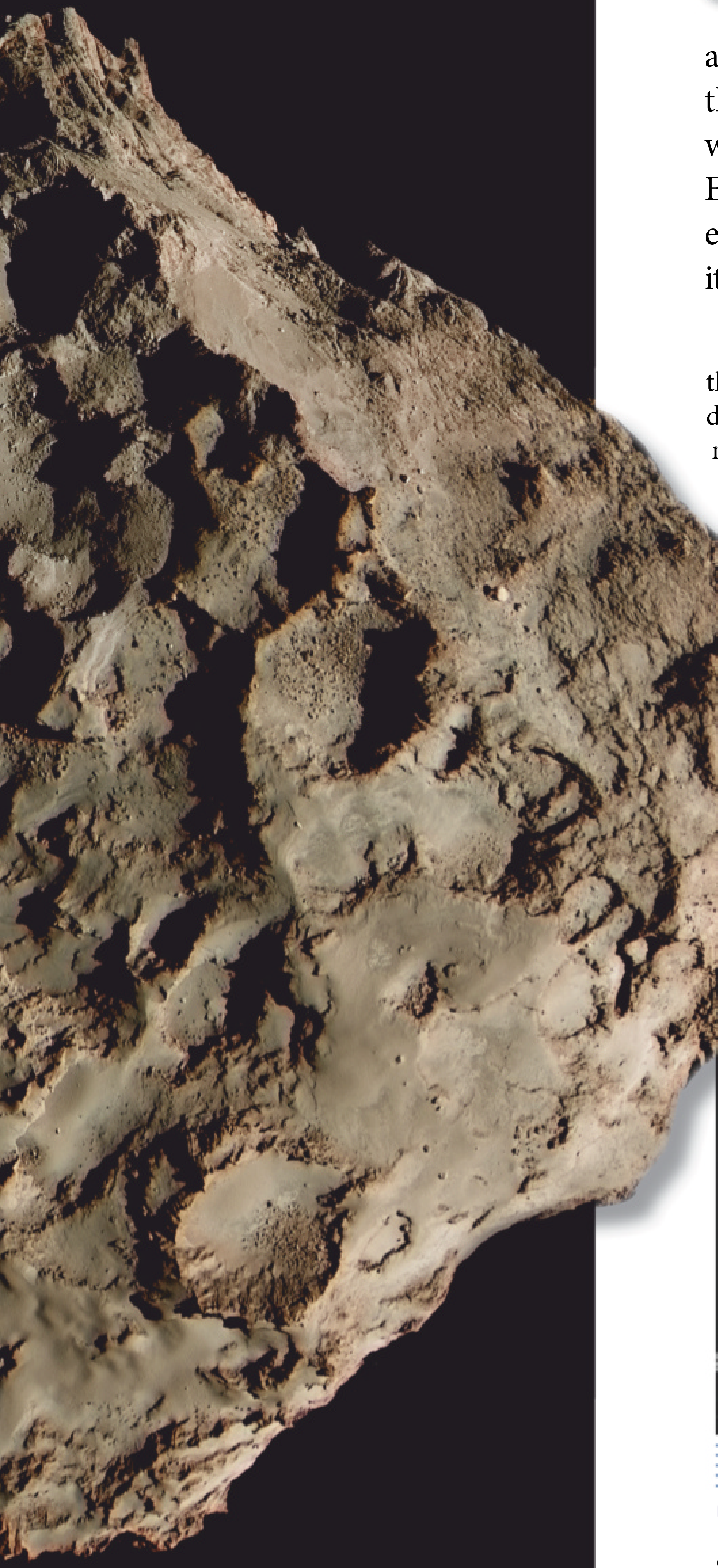
The SCIENCE of COMETS

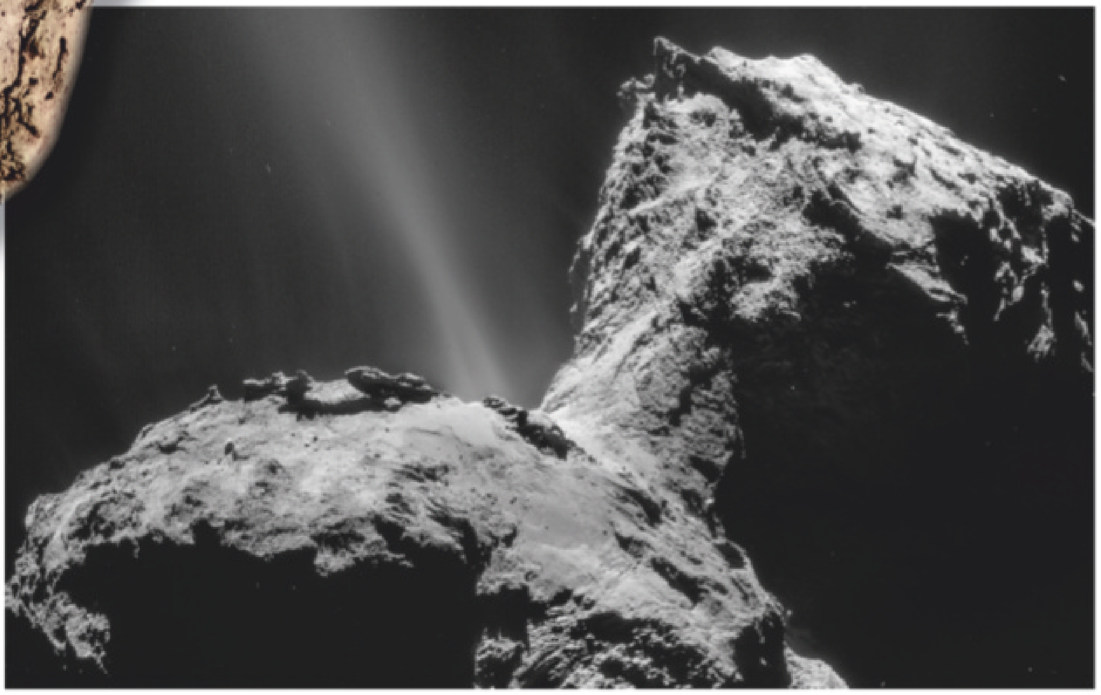
THE WORLD OF COMETS

LAST YEAR, 2022, MARKED 30 YEARS since the first discovery of a member of the Kuiper Belt beyond Pluto, 1992 QB_1, by astronomers David Jewitt and Jane Luu. The presence of this small world, roughly 60 miles (100 kilometers) across, wasn't entirely unexpected; the Irish astronomer Kenneth Edgeworth had suggested a population of such objects could exist beyond Neptune nearly 50 years earlier. Nevertheless, it was an impressive feat of perseverance and technical skill.

It also marked a turning point in the study of comets. The last three decades have brought a torrent of new discoveries that have transformed our understanding of where cometary bodies reside, how they got there, and how they continue to evolve.

Thanks to an expanding network of progressively more powerful surveys and telescopes, we now have identified several thousand Kuiper Belt objects (KBOs), along with hundreds of Centaurs — cometary bodies occupying unstable orbits that ricochet among the giant planets. When these objects are perturbed and sent sailing into the inner solar system, they are heated by the Sun and transformed into the ethereal apparitions we know as comets. Surveys now routinely discover incoming comets as they pass through the outer regions of the solar system and monitor how they evolve as they approach and then depart the inner solar system.





COMPLEX WORLD • LEFT: The comet 67P/Churyumov-Gerasimenko has cliffs, boulders, pits, and pock-marks — all on a "dirty snowball" just 2.7 miles (4.3 km) across. ESA/ROSETTA/MPS FOR OSIRIS TEAM (MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA)/JUSTIN COWART; CC BY-SA 4.0

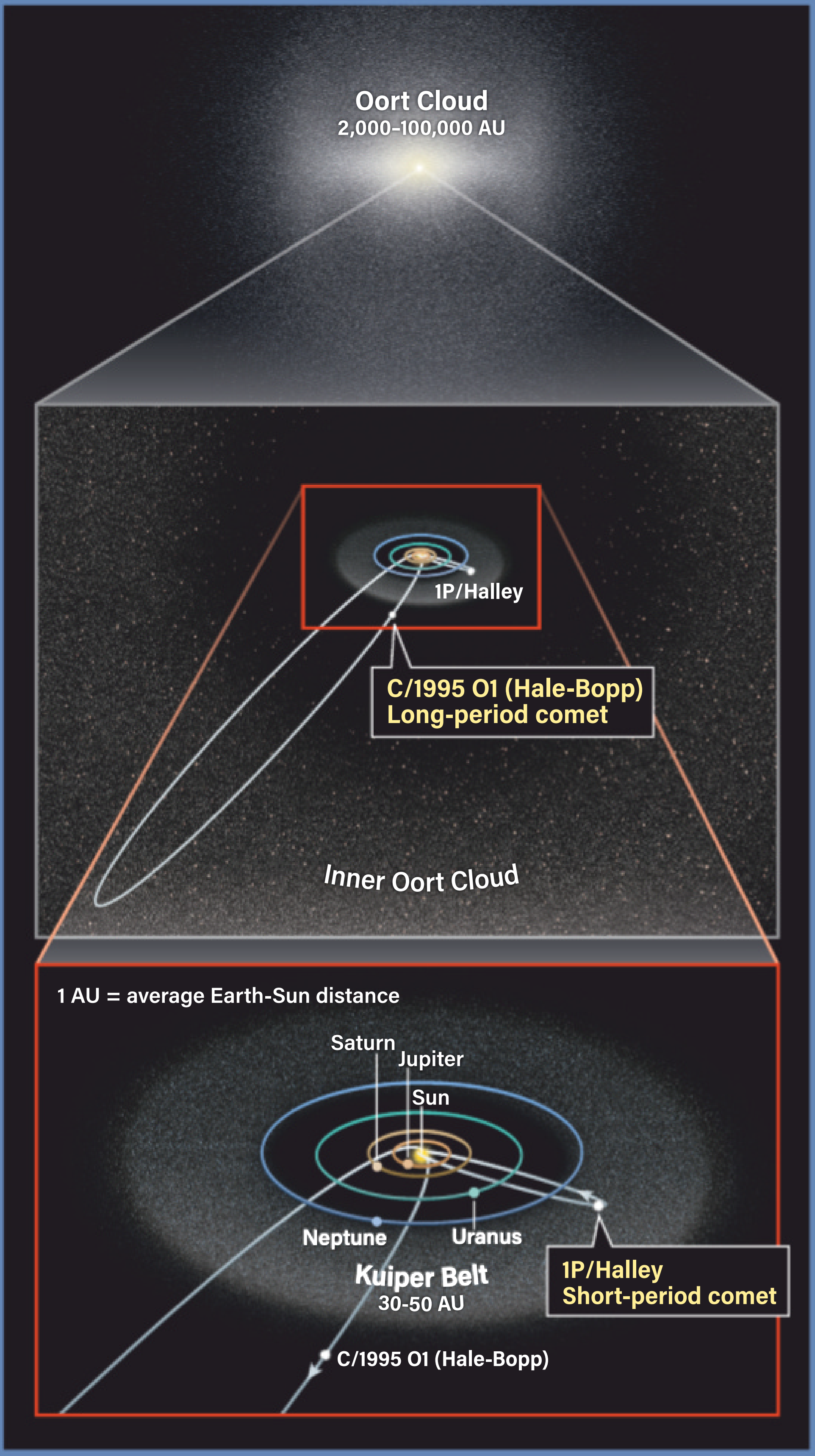
ABOVE: Gas and dust stream away from 67P/Churyumov-Gerasimenko in this mosaic created from four panels taken by Rosetta at a distance of 17 miles (28 km) from the comet. ESA/ROSETTA/NAVCAM – CC BY-SA IGO 3.0

COMET CRESCENT
• Comet 67P/Churyumov-Gerasimenko releases streams of gas and dust into space in this false-color image taken by ESA's Rosetta spacecraft. ESA, ROSETTA, NAVCAM; PROCESSING BY GIUSEPPE CONZO; CC BY-SA IGO 3.0

The last 20 years have also been a golden age of comet exploration with spacecraft. Since Deep Space 1's flyby of 19P/Borrelly in 2001, we have had close encounters with six cometary bodies. They include NASA's Deep Impact mission, which struck the surface of Tempel 1 (9P/Tempel) with an 816-pound (370 kilograms) impactor; the European Space Agency's (ESA) Rosetta spacecraft, which spent two years exploring 67P/Churyumov-Gerasimenko; and NASA's New Horizons mission, which, after passing by Pluto in 2015, buzzed the KBO Arrokoth in 2019. These encounters have revealed icy planetesimals to be astonishingly complex worlds that vary in shape, geology, and activity, with no two objects fully alike.

These advances have been reinforced by tools that can identify more complex gases in comae — the fuzzy atmospheres that surround comets as gases vent and evaporate. And since 2011, the Atacama Large Millimeter/submillimeter Array in Chile has been imaging planet-forming disks around other stars, providing additional context to the histories of these small icy bodies.

COMET CLASSES


Oort Cloud
2,000-100,000 AU
1P/Halley
C/1995 O1 (Hale-Bopp)
Long-period comet
Inner Oort Cloud
1 AU = average Earth-Sun distance
Saturn
Jupiter
Sun
Neptune
Uranus
Kuiper Belt
30-50 AU
1P/Halley
Short-period comet
C/1995 O1 (Hale-Bopp)

OUR SOLAR SYSTEM HAS two reservoirs that produce different classes of comets. Short-period comets — those that orbit the Sun in less than 200 years — come from the scattered disk, which consists of objects that circulate among the Kuiper Belt but in orbits that are more elliptical and tilted than typical Kuiper Belt objects. Long-period comets are thought to come from the Oort Cloud, which extends upward of 1 light-year in all directions from the Sun.

ASTRONOMY: ROEN KELLY

It may seem that with all we've learned since the discovery of QB_1, the most important questions about comets have been answered. And yet, many of the key properties of comets remain a mystery. As primordial leftovers from the formation of our planetary system, they also happen to be the best available avenue for exploring its origins. With that in mind, here are just a few of the questions that have yet to be answered.

What are comet interiors like?

The first modern description of a comet nucleus was suggested by Fred Whipple in the 1950s. In his model, a comet was a more or less uniform body that he called an "icy conglomerate," composed of various ices mixed with dust. The press dubbed it the "dirty snowball" hypothesis. While this could explain cometary activity, it did not fit our emerging understanding of comets as bodies nearly devoid of internal strength that occasionally disintegrate of their own accord when merely warmed by the Sun.

Spacecraft encounters with comets have revealed astonishingly complex worlds, with no two objects fully alike.

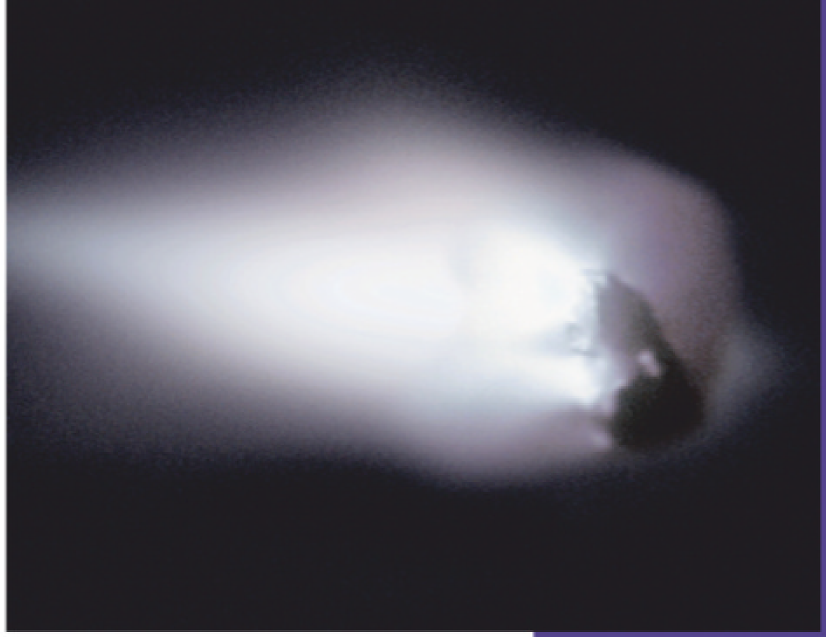
In 1986, Paul Weissman proposed that comets were instead "rubble piles" of loosely bound, smaller bodies of various sizes. These pieces of rubble would have had to collide at very low velocities and been in largely similar orbits to avoid destroying each other.

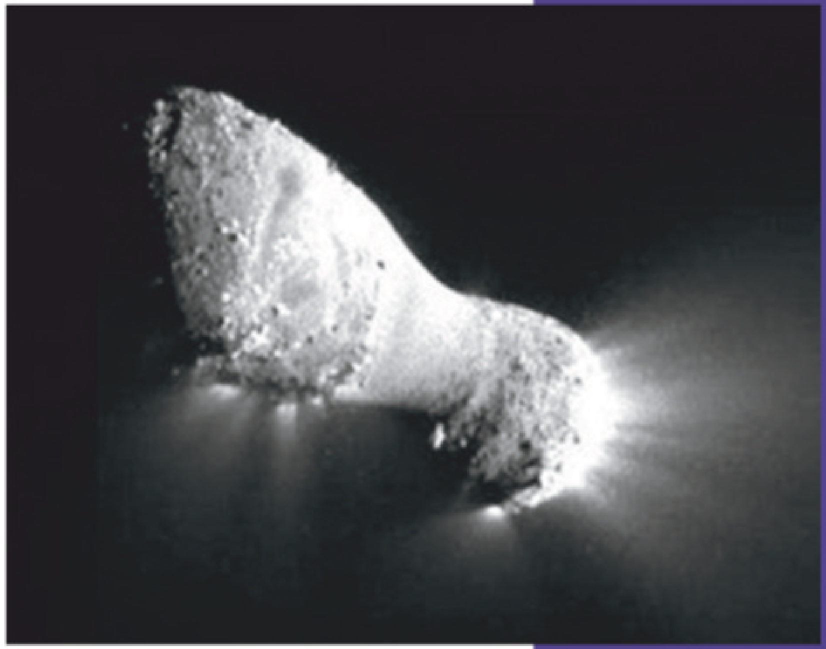
Modern models for comet formation are based on one of two ideas. The first is that, when the Sun was still forming, instabilities developed in the surrounding disk of material. These instabilities could have been caused by a variety of processes, but the end result is pockets of high density where collections of smaller objects become gravitationally attracted to each other and coalesce.

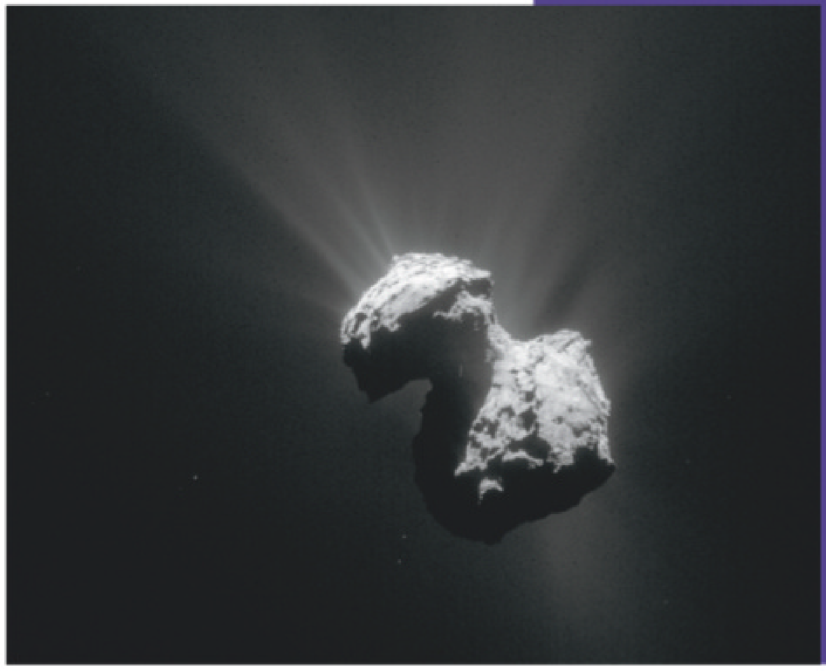
The second is radial drift, which occurs as forming particles grow to meters in diameter. At this point, drag causes them to slowly drift inward toward the Sun, attaching to other small bodies as they go.

Both of these mechanisms can form rubble-pile comet nuclei with the properties we observe, including low overall densities and constituent particles that have virtually no bond between them. However, the properties of the components depend on assumptions about the conditions under which they formed. Some models predict a nucleus composed of a uniform mix of smaller particles of similar sizes, while others imply a mix of sizes ranging from 1 to hundreds of meters in diameter. Yet another model predicts that comet nuclei form when higher-velocity impactors accumulate, compressing one another to form a layered interior rather than a rubble pile.

Unfortunately, it is difficult to tell the difference between various formation models even when we visit a comet up close. However, we are occasionally provided with clues we try to interpret. In 1992, Comet Shoemaker-Levy 9 experienced a close encounter with Jupiter where tidal forces tore it apart into 21 smaller fragments, which famously impacted Jupiter two years later. But in between, we were able to watch the fragments spread out along the comet's orbit. The sizes of the individual fragments varied considerably, with estimated diameters ranging from 330 feet (100 meters) to 2.5 miles (4 km). These sizes may have been





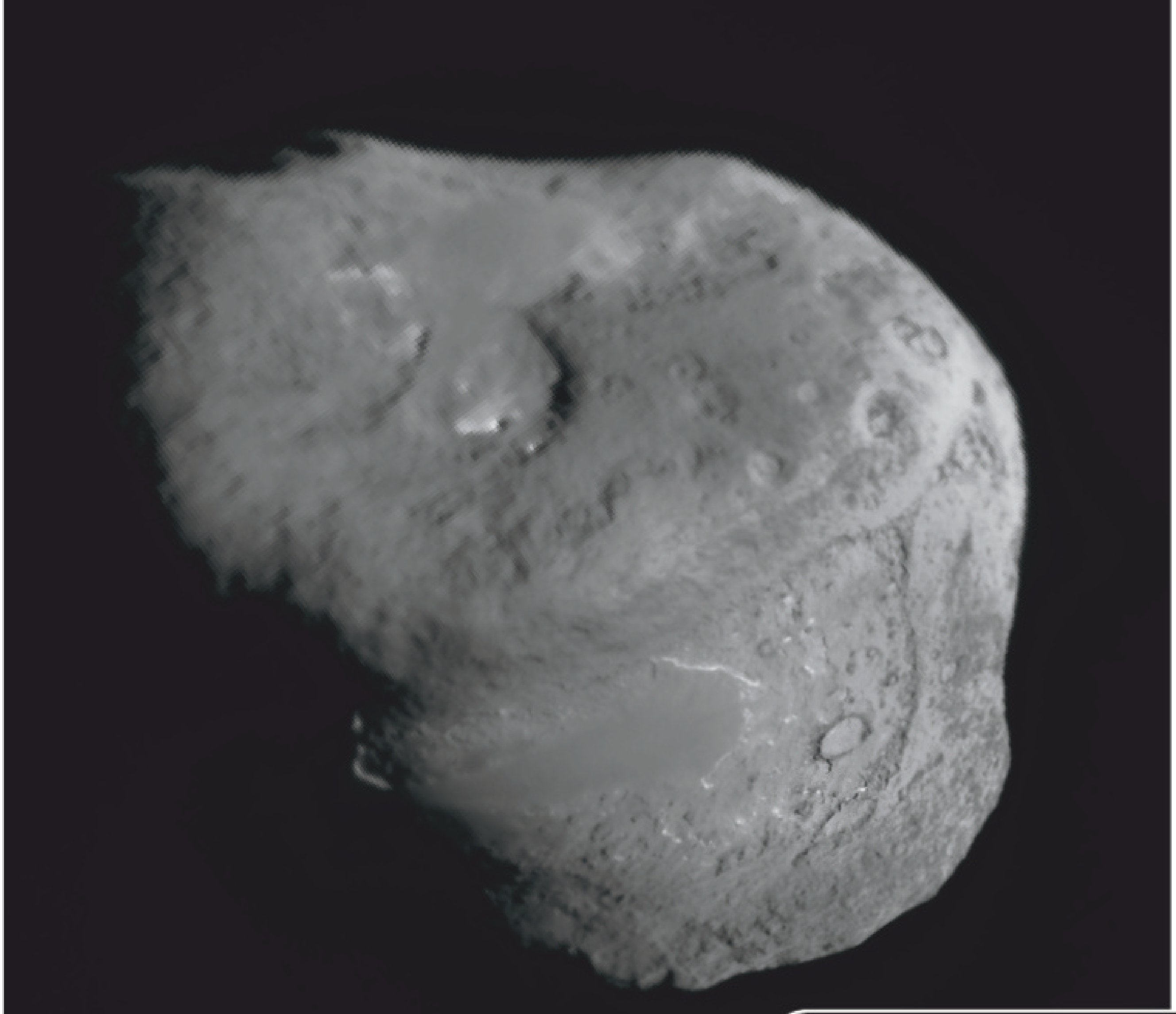


TOP TO BOTTOM:

HALLEY • When Comet 1P/Halley returned to the inner solar system in 1986, it was met by an international fleet of spacecraft representing countries including the U.S., Japan, and Soviet Union. But it was the European probe Giotto that made the most daring excursion, buzzing Halley at a distance of under 370 miles (600 km) and taking some of the first-ever close-up pictures of a comet nucleus. NASA/ESA/GIOTTO PROJECT

HARTLEY 2 • After Deep Impact successfully struck 9P/Tempel, the spacecraft took on a second assignment and flew by 103P/Hartley, a 1-mile-wide (1.6 km) comet that orbits within the asteroid belt. It found jets of carbon dioxide shooting out from the ends of the comet nucleus, but water vapor coming off its narrower midsection. NASA/JPL-CALTECH/UMD

67P • 67P/Churyumov-Gerasimenko vents into space in this single frame taken by Rosetta at a distance of 96 miles (154 km) from the comet. ESA/ROSETTA/NAVCAM – CC BY-SA IGO 3.0



BULL'S-EYE • NASA's Deep Impact mission sought a glimpse of the interior of Comet 9P/Tempel by releasing a high-speed impactor that smashed into its surface July 4, 2005, producing a flash of scattered light (inset). The larger mosaic of Tempel 1 (above) is constructed from images collected by the impactor on its way to the surface. NASA/JPL-CALTECH/UMD

evidence of the makeup of the original interior of the comet. However, it's also possible they resulted from a different process related to the tidal disruption.

Subsequent missions to comets Hartley 2 (103P/Hartley) and 67P/Churyumov-Gerasimenko may have revealed evidence for a different formation process. The crowded halo of debris surrounding 103P contained objects as large as 1 foot (30 centimeters) in diameter; some researchers have suggested these are representative of the small pebbles from which the comet's nucleus is assembled. Rosetta found a similar situation at Churyumov-Gerasimenko, where meter-sized "goosebump" features stacked along the walls of eroded pits on the surface appear to be examples of the primordial bricks making up the comet. Also at Churyumov-Gerasimenko, observers mapped what appeared to be a succession of layers on the surface that had been exposed as the comet evolved, leading some to suggest they were evidence for its formation via compressive impacts.

Ultimately, the only definitive way to understand a comet's interior is to measure it directly. Short of burrowing in, our best method for doing so is to map the nucleus using radar. We actually came very close to doing this at Churyumov-Gerasimenko. The orbiting Rosetta spacecraft had a detachable lander, Philae, that was intended to serve as half of a bistatic radar mapping experiment. Unfortunately, that opportunity was dashed when Philae settled on the surface in a shadowed region where it could not recharge its batteries. Only a single measurement was made before the lander lost power.

Despite this, we haven't given up. Scientists continue to develop new radar experiments that we hope to one day fly to another comet.

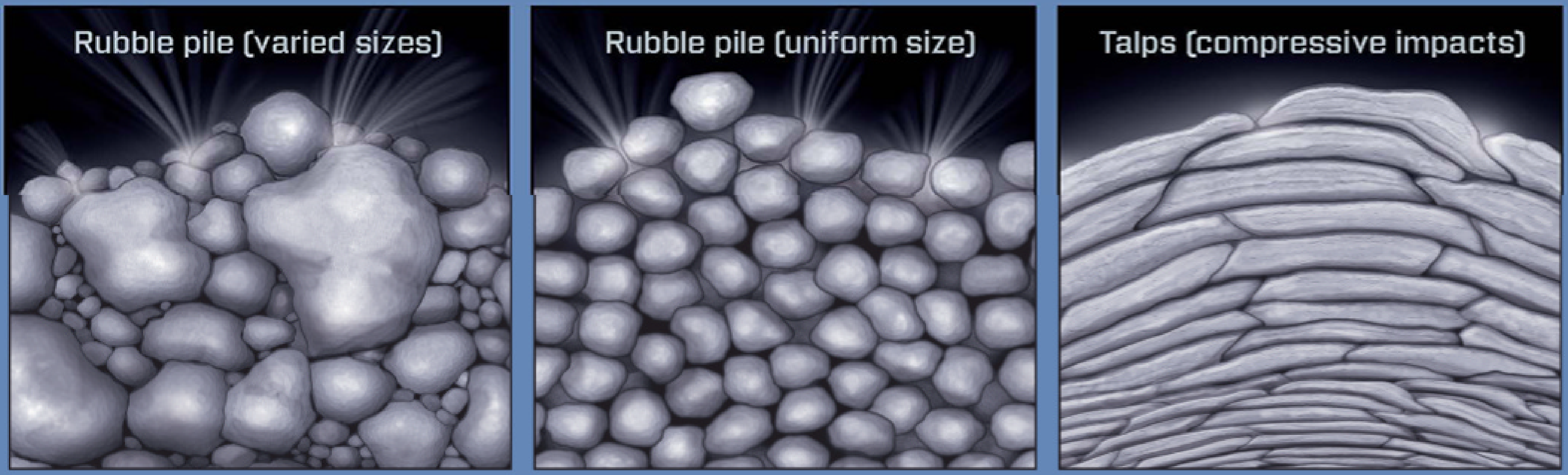
Why do comets outburst?

In 2007, Comet 17P/Holmes treated observers to an amazing display when it suddenly brightened by 14 magnitudes (a factor of nearly 500,000!) in 42 hours to become a naked-eye object that slowly faded over the next several months. This event was an extreme example of a cometary outburst, an explosion of activity releasing huge amounts of dust and gas from the nucleus.

Large outbursts like these occur seemingly at random: Some comets experience major events at several locations along their orbit, while others pass by the Sun in quiescence. This mercurial nature makes it very difficult to study outbursts. Of our spacecraft envoys, none has yet been present at the time of a large outburst, although Rosetta and Deep Impact both observed multiple small outbursts during their encounters with Churyumov-Gerasimenko and Tempel 1 (9P/Tempel), respectively. This suggests outbursts may be more common than we thought.

Their root causes, however, remain a mystery. Scientists have proposed various mechanisms, including large-scale geologic events like landslides, subsurface gas pockets exploding to the surface, and chemical reactions that rapidly unleash stored internal energy. It's possible that all of these contribute to outburstlike phenomena in different situations, but the release of chemical energy may best explain very large events like the one from Holmes, those occurring farthest from the Sun, and outbursts where the energy of ejected

INSIDE COMETS

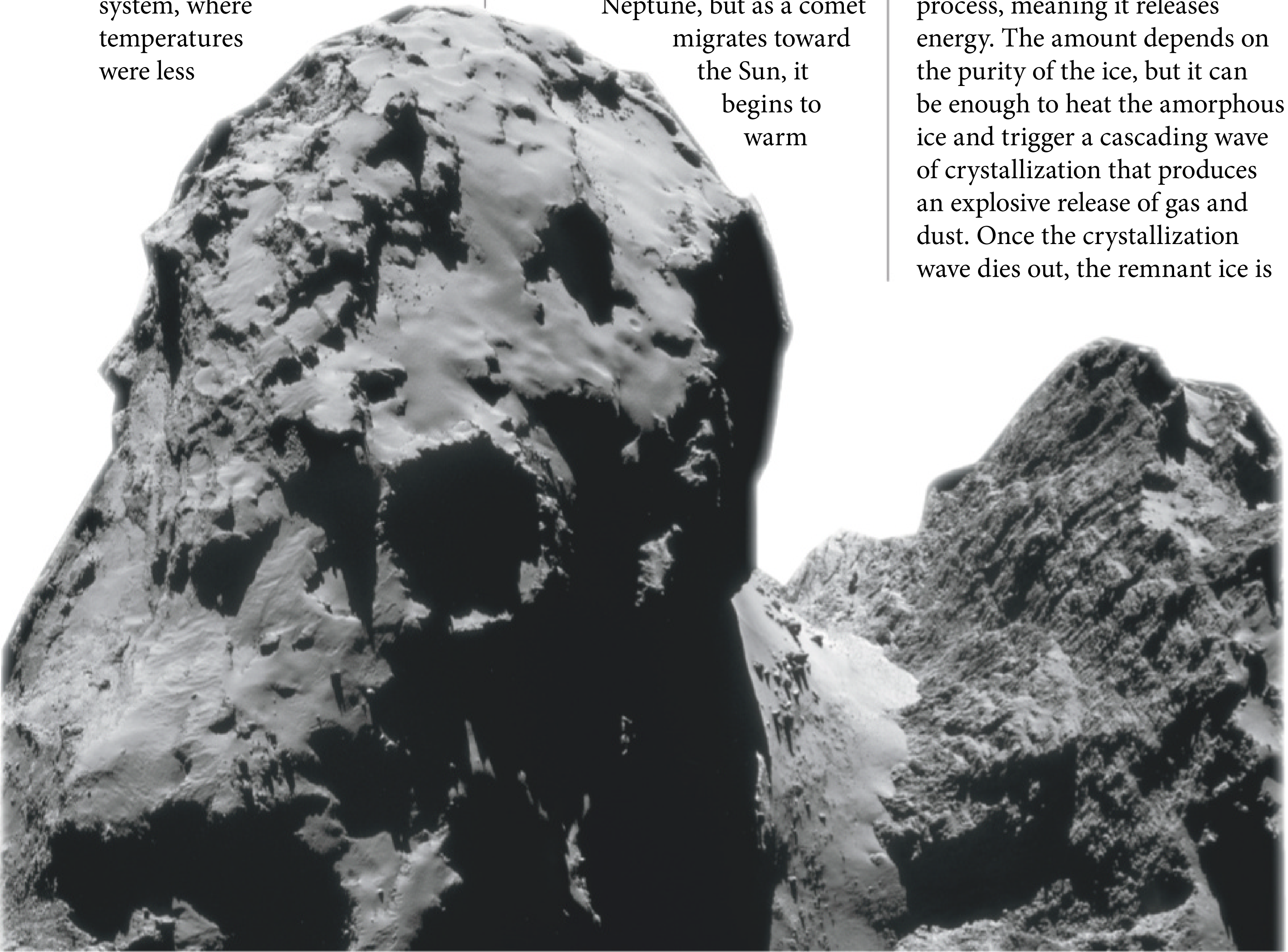

Rubble pile (varied sizes)
Rubble pile (uniform size)
Talps (compressive impacts)

IN THE RUBBLE-PILE MODEL of comet nuclei, the fragments of the comet are held together by little more than the extremely weak gravity between them. These fragments may be of disparate sizes (left) or have a similar, characteristic size (center). In these formation models, comet nuclei can only form through very gentle collisions. Alternatively, small fragments of ice and dust may pelt one another in higher-speed collisions and flatten themselves upon impact into a series of layers called talps (right). *ASTRONOMY*: ROEN KELLY

material is substantially greater than what solar heating alone can provide.

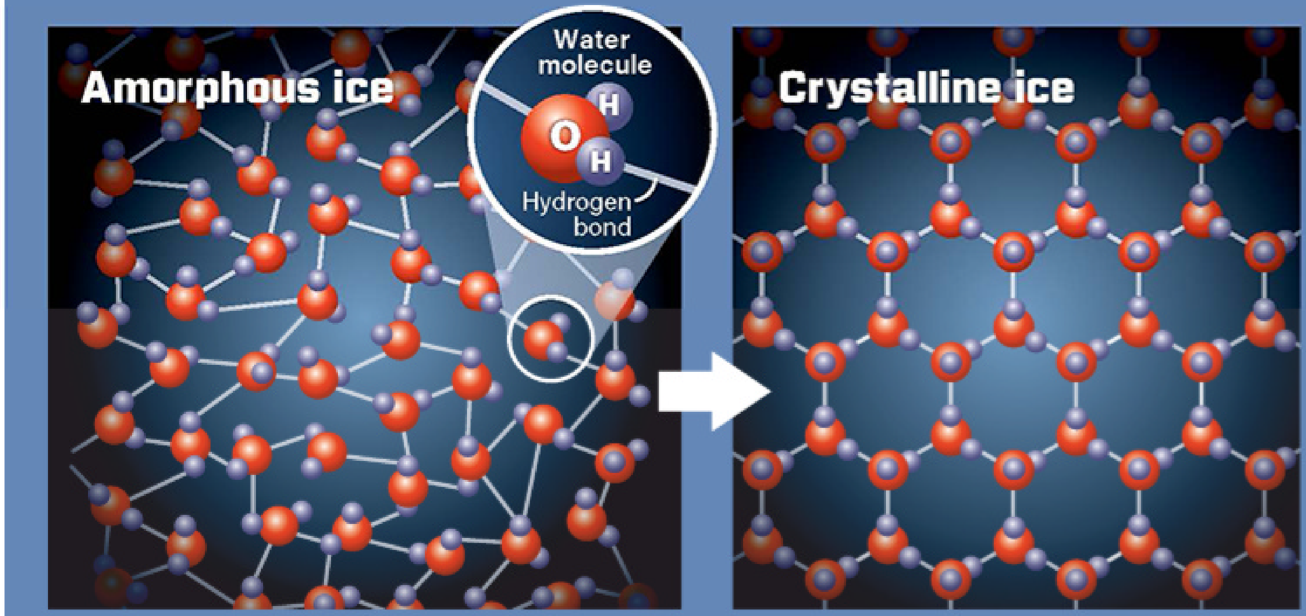
The chemical process most frequently invoked is the transformation of water ice from an amorphous to crystalline state. Amorphous water ice condensed onto dust grains in the coldest parts of the early solar system, where temperatures were less than –387 degrees Fahrenheit (–233 degrees Celsius). At these temperatures, there isn't enough energy for water to arrange itself into an organized crystal, so it assumes a disorganized form, inside which it is able to trap large quantities of gas. The amorphous state is stable in the frigid outer solar system beyond Neptune, but as a comet migrates toward the Sun, it begins to warm until its water can reorganize itself into the crystalline matrix of ice we're familiar with.

When this occurs, two things happen. First, most of the gases trapped in the amorphous ice are released because the crystalline state has less room to contain them. Second, the transition to crystalline ice is an *exothermic* process, meaning it releases energy. The amount depends on the purity of the ice, but it can be enough to heat the amorphous ice and trigger a cascading wave of crystallization that produces an explosive release of gas and dust. Once the crystallization wave dies out, the remnant ice is



ROCKY TERRAIN • This sunlit valley on 67P/Churyumov-Gerasimenko is lined by jagged cliffs roughly 0.6 mile (1 km) high. ESA/ROSETTA/NAVCAM – CC BY-SA IGO 3.0

TWICE AS ICE



AMORPHOUS ICE CAN FORM at temperatures below about –215 degrees Fahrenheit (–137 degrees Celsius), and has no organization or structure (left). But when it is heated above that temperature — like when a comet nears the Sun — the molecules can suddenly rearrange themselves into the hexagonal structure of crystalline ice (right). This phase transition releases energy and also causes the material to expand, which could help power large comet outbursts. *ASTRONOMY*: ROEN KELLY

stable, and normal comet activity can occur.

The best way to test hypotheses for large-scale outburst activity is to be physically present when the event occurs. Their random nature makes this challenging, but there are some targets where we are likely to be successful — like the Centaur 29P/Schwassman-Wachmann, which lies in a nearly circular orbit just beyond Jupiter and experiences major outbursts about seven times a year.

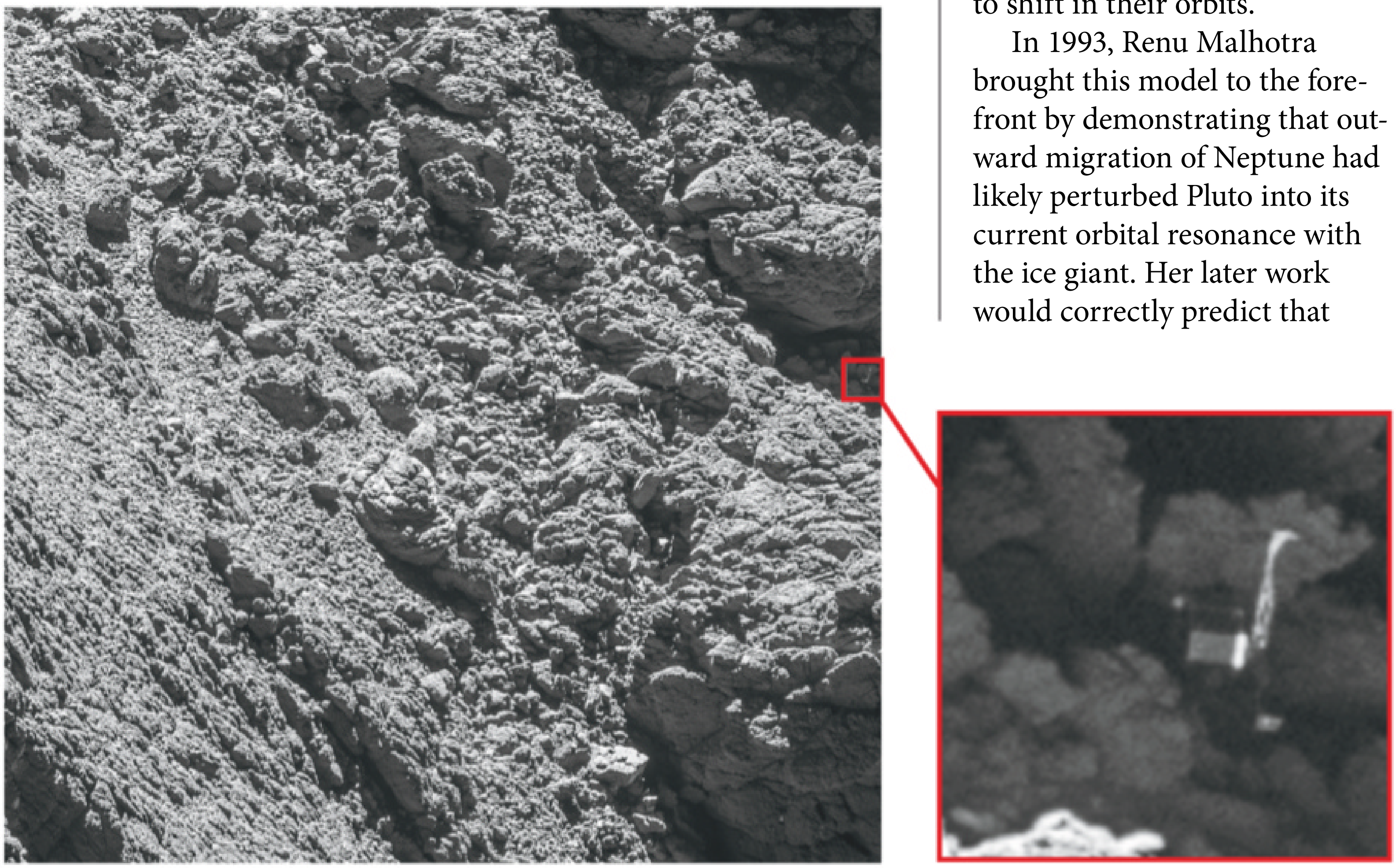
How do dynamical classes of comets differ?

A less obvious milestone in the study of comets came only three years after the discovery of 1992 QB$_1$, when 51 Pegasi b became the first confirmed planet around another Sun-like star. We now know of nearly 4,000 stars with at least one planet, and several thousand additional candidate systems have ongoing follow-up studies.

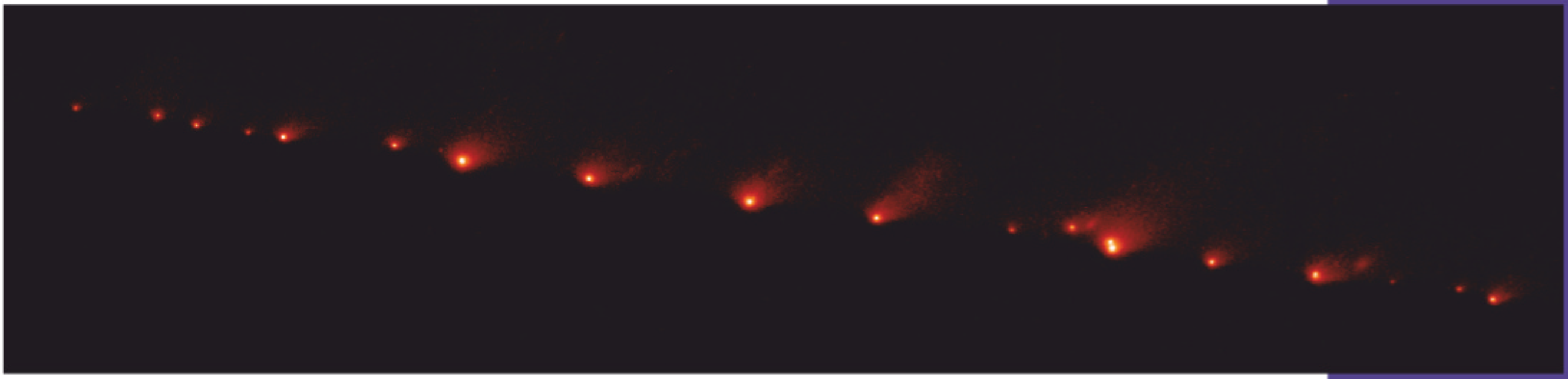
These systems display tremendous diversity, with many planets occupying strange orbits that were difficult to reconcile with the conventional wisdom of the early 1990s for how our solar system formed. 51 Peg b was the first example of what we now call hot Jupiters — planets the mass of Jupiter or greater that hug their stars in orbits tighter than Mercury's. Hot Jupiters showed us that planets can form in one place in their system but, over time, migrate to a completely different region.

The significance of migration to comets was first discussed a decade earlier by Julio Fernández and Wing-Huen Ip in a 1984 paper in the journal *Icarus*. They suggested that when comets are perturbed by the outer planets and scattered across the solar system, the resulting transfer of angular momentum would cause the giant planets to shift in their orbits.

In 1993, Renu Malhotra brought this model to the forefront by demonstrating that outward migration of Neptune had likely perturbed Pluto into its current orbital resonance with the ice giant. Her later work would correctly predict that



RESTING PLACE • Philae was a small lander just over 3 feet (1 m) wide that accompanied Rosetta to 67P/Churyumov-Gerasimenko and touched down Nov. 12, 2014. Unfortunately, it was unable to recharge its batteries effectively and quickly fell out of regular contact. In the final month of Rosetta's mission, the craft finally identified where Philae had come to rest: wedged deep in a crack where sunlight couldn't reach it. ESA/ROSETTA/MPS FOR OSIRIS TEAM MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA; CONTEXT: ESA/ROSETTA/NAVCAM – CC BY-SA IGO 3.0



BREAKUP • TOP: A close encounter with Jupiter — and the accompanying tidal forces — caused comet Shoemaker-Levy 9 to fragment, as captured in this Hubble Space Telescope image. NASA, ESA, AND H. WEAVER AND E. SMITH (STSCI)

Neptune was the key to the entire organization of the Kuiper Belt. Its motion and gravitational influence formed a scattered disk of small bodies that were forced outward by migration and clustered KBOs in orbital resonances.

The dynamical class of a comet refers to the reservoir from which it was perturbed into the inner solar system. The two major groups are the short-period comets (SPCs), with orbital periods up to about 200 years, and the long-period comets (LPCs), with periods from a few hundred to several tens of thousands of years. The SPCs come from the Kuiper Belt, specifically the scattered population driven there by Neptune's migration. The LPCs come from the outer regions of the Oort Cloud, a uniform distribution of small bodies that stretches from a few thousand times the distance between the Sun and Earth out to more than a light-year away. Both of these reservoirs are thought to have been scattered to their modern orbits by the giant planets.

> Centaurs are the parents of short-period comets and may be our best opportunity to answer some of our most basic questions about comets.

This is what makes comets so helpful in understanding the history of our solar system: The characteristics of a comet depend on the conditions within the primordial planetary disk where it formed, as well as how they were scattered to their modern location. When they return toward the Sun as comets, the physical properties of the dust and gas they release provide clues about the turbulent early history of the solar system.

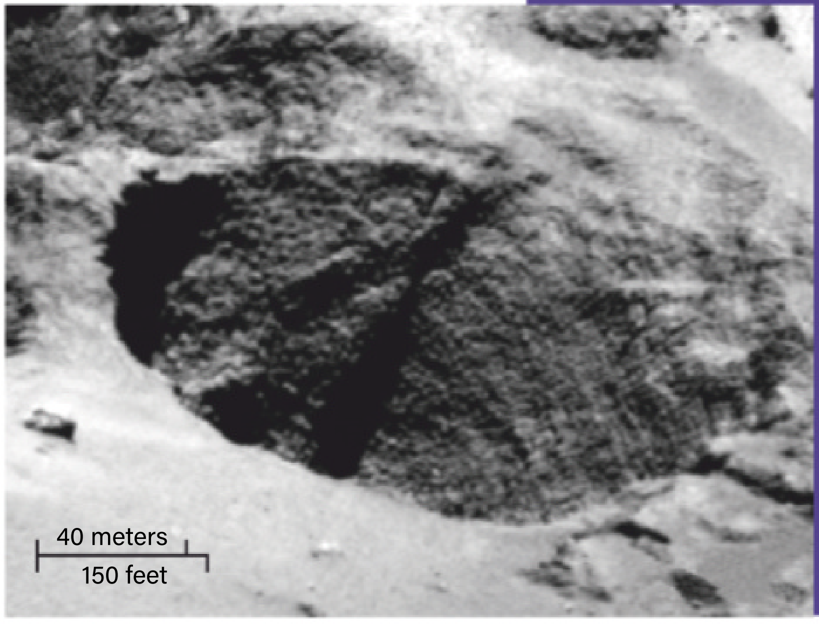
For instance, the discovery of main-belt comets — a dynamical class of nearly dormant ice-rich bodies that reside in the asteroid belt — suggested that Jupiter forced icy bodies into the inner solar system. This also suggested the opposite process as well: that Jupiter scattered asteroids out into the Oort Cloud. In fact, some models predict that as much as a few percent of the Oort Cloud may originally have been asteroids. This was lent credence in 2016 when a team led by Karen Meech of the University of Hawaii reported that C/2014 S3 (PanSTARRS) was an inactive object with the orbit of an LPC but the composition of an asteroid.

Coming attractions

The coming years should be full of cometary advances.

The pace of discovery of KBOs shows no signs of slowing, and the 8.4-meter Vera C. Rubin Observatory in Chile, set to start operations in 2024, promises to uncover ever smaller and more remote objects.

Spacecraft will also continue to venture to comets. NASA's Lucy mission, launched in 2021, is en route to the Trojan asteroids, which orbit in the vicinity of Jupiter and are thought to be captured KBOs. In 2022, the planetary science community recommended NASA prioritize a Centaur-lander mission, and concepts to visit 29P/Schwassman-Wachmann have been proposed. And ESA is developing the Comet Interceptor mission, which will launch toward the end of this decade and wait for a pristine long-period comet — perhaps even an interstellar visitor like 'Oumuamua or Borisov — to appear.



SKIN DEEP • ABOVE: Some scientists think that the "goosebumps" texture seen on the inside wall of this eroded pit at Comet 67P/Churyumov-Gerasimenko is evidence that comets are made of pebbles of a uniform size. ESA/ROSETTA/MPS FOR OSIRIS TEAM MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

As these initiatives unfold, there are sure to be surprises. One of the truisms of solar-system exploration is that close-up looks at our neighbors raise as many questions as they answer, often upending our conventional wisdom. This has certainly been true of comets — and will likely be true yet again.

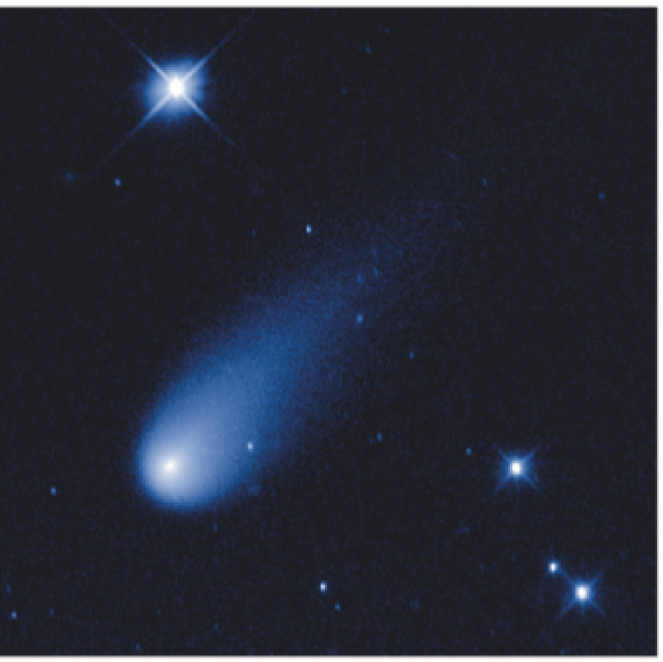
Walter Harris *is a professor in the Lunar and Planetary Laboratory at the University of Arizona. He has been studying comets for over 25 years.*

How to OBSERVE

Whether viewed through binoculars or a telescope or with your naked eyes, tracking down these celestial visitors is a rewarding challenge. **BY STEPHEN JAMES O'MEARA**

THE WORLD OF COMETS

LUCKY ARE THOSE who have seen a great naked-eye comet, one with a head and tail so intense that you need only look up to see it. It's a rarity: On average, such a comet — brighter than magnitude 0 — appears once every 15 years. Fortunately, several fainter comets that are visible through binoculars or small- to medium-sized telescopes grace the skies each year.



ABOVE: Comet C/2012 S1 (ISON) had a simple form that readily showed off the major parts of a comet: head and tail. NASA, ESA, AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

RIGHT: Comet C/2020 F3 (NEOWISE) was a queenly apparition of gentle splendor enjoyed by many. Although some people spied it with their unaided eyes, it was to many a binocular wonder. STEPHEN JAMES O'MEARA

To many, hunting down and monitoring these fuzzy, frozen fragments left over from the formation of our solar system is one of the most satisfying pastimes of our hobby, linking us to celestial sights that have influenced humanity throughout the ages. And for those wishing to get into the exciting pursuit of observing comets, here's what you need to know.

Start a comet watch

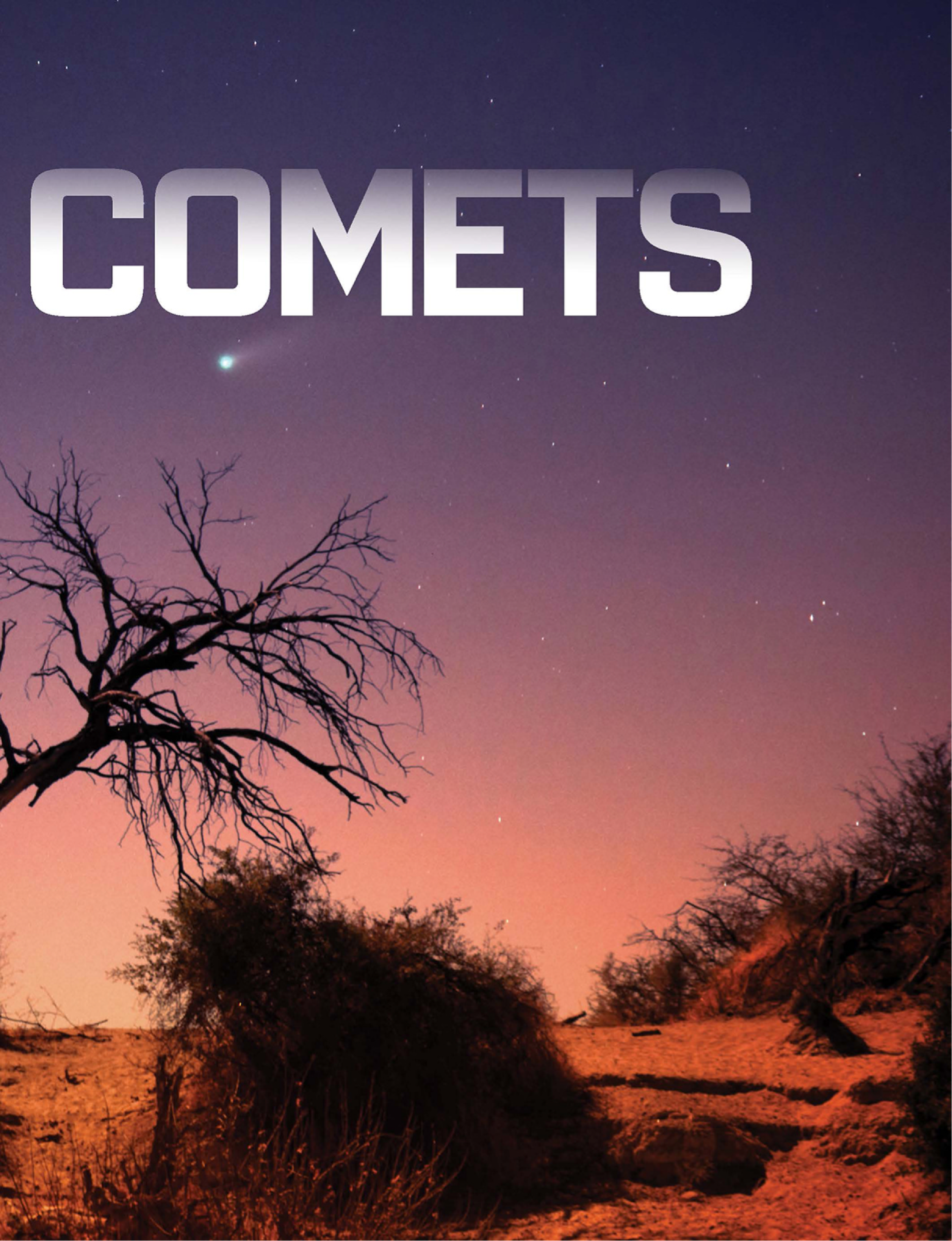
Most serious comet-watchers monitor the brightness and extent of a comet's two main features: its head and its tail. By studying them, astronomers can gain a better understanding of how comets shed their dust and release their gas.

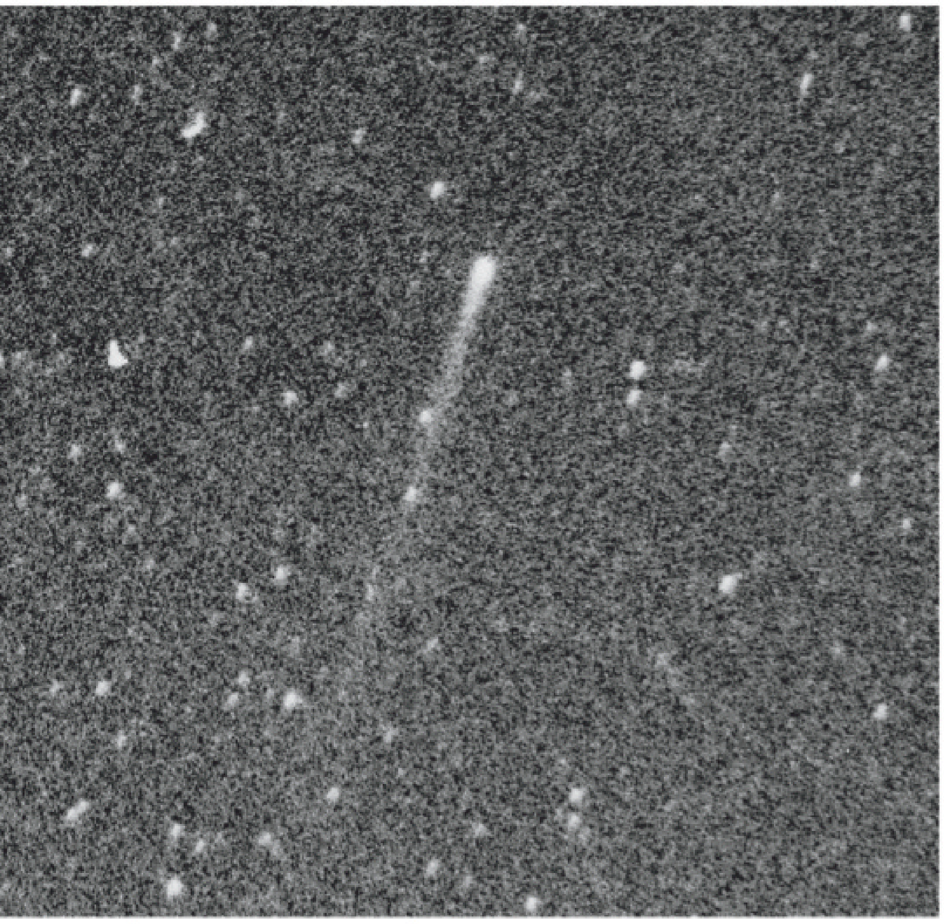
The head is made of a diffuse shell of dust and gas (the coma; Latin for "hair of the head") and a starlike core (the pseudo-nucleus). A comet's tail can include a dust tail, an ion tail, or both.

While brighter comets can be superb sights to the unaided eyes or binoculars, most telescopic comets appear as breathy glows whose shapes and sizes mimic faint star clusters or dim face-on galaxies. Yet comets also possess an almost mystical allure, shining with a neighborly light that distant deep-sky objects cannot replicate. Like planets, comets primarily shine by reflecting sunlight. They also wander across the starry background sky, changing position slightly night after night.

But comets can also change their appearance on a whim — that's what makes them so exciting to observe! A comet may suddenly surge

COMETS





ABOVE LEFT: Hailed as the comet of the century, C/1973 E1 (Kohoutek) only reached a total visual magnitude of 0. In this December 1973 shot from Haleakala, Hawaii, the comet's visible tail stretches some 10 million miles. NASA/FRANK GIOVANE

ABOVE RIGHT: In February 1976, Comet C/1975 V1 (West) was 4th magnitude when it unexpectedly flared in brightness just prior to its perihelion passage, when the author and Peter Collins at Harvard College Observatory observed it shining at magnitude –3 in broad daylight through a 3-inch finder scope. J. LINDER/ESO

BOTTOM ROW, FARTHEST LEFT: Comet C/2017 K2 (PanSTARRS) moves against the stars over the course of four consecutive June 2022 nights in this composite image. The loose open star cluster IC 4665 in Ophiuchus is at upper left; bright Cebalrai (Beta [β] Ophiuchi) is at upper right. STEPHEN JAMES O'MEARA

in brightness overnight or fizzle out in just a few short days. One important aspect of observing comets, then, is to estimate the brightness of the comet's coma.

Checking recent reports for the brightness of comets can help you to decide which objects to pursue, as only you know the limits of your equipment. While recent observations are useful as selection guides, do not rely on them when you go out to observe. Comets are as predictable as uninvited house guests. One key resource for accurate information regarding news, observations, orbital data, designations, and names — as well as good links for comets and related topics — is *The International Comet Quarterly (ICQ) Comet Information Website* (www.icq.eps.harvard.edu).

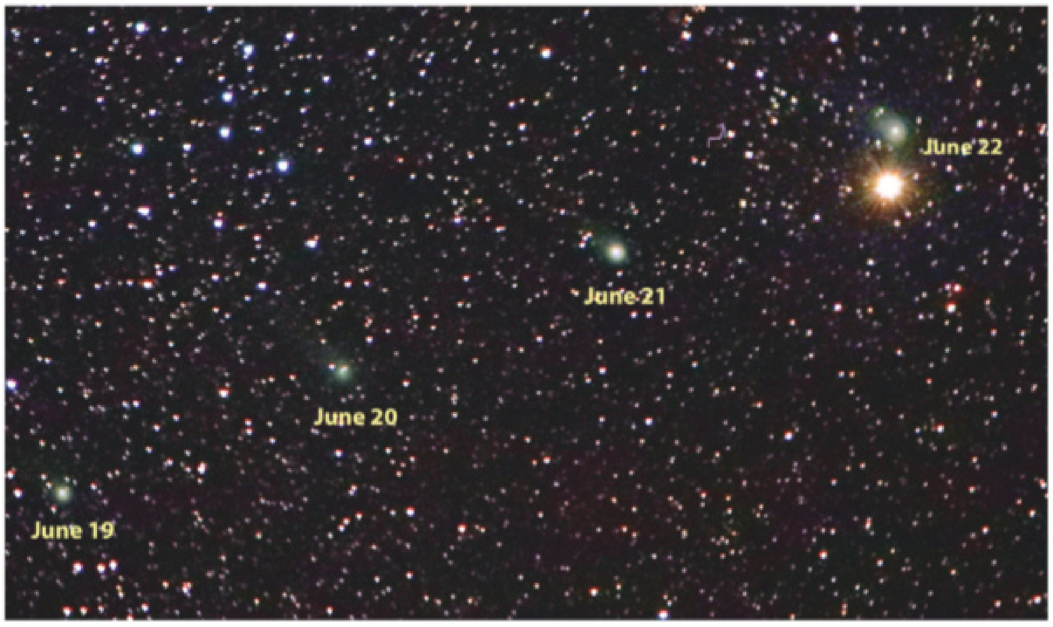
Estimating magnitude

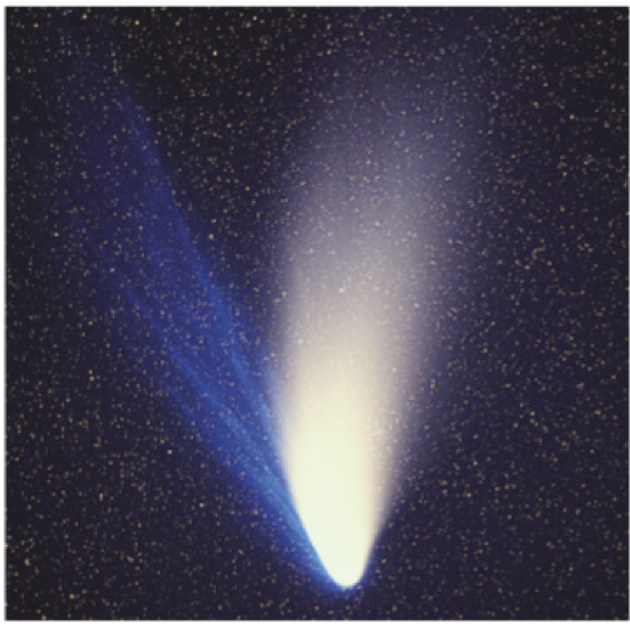
Determining a comet's brightness starts with an assessment of its apparent size and its degree of condensation (DC), a measure of how tightly concentrated the light from the coma appears. The coma may be anywhere from a few arcminutes to several degrees in apparent size, while the DC value varies from 0 to 9.

DC = 0 represents a comet with a uniformly diffuse coma, with no discernible brightening from the outer edge of the coma to the center. DC = 5 means the comet is moderately condensed, showing a distinct brightening toward the center. DC = 9 represents a nearly stellar appearance, where almost all the brightness is concentrated at a central point or within a tiny disk; this is hardly ever seen.

While all DC values are somewhat subjective because they depend heavily on the brightness of the background sky, they, in combination with a comet's size, will help you determine which specific method to use when estimating the brightness of a comet's coma. The ICQ recommends the following three methods:

In-Out (Vsekhsvyatskij-Steavenson-Sidgwick [VSS]) method: This approach is best





for diffuse comets that do not display a strong central condensation (i.e., those with low DC values). The observer compares an in-focus image of the comet to nearby comparison stars that have been defocused to appear the same size as the comet's coma.

Out-Out (Van Biesbroeck-Bobrovnikoff-Meisel [VBM]) method: This is the easiest method to use and is appropriate for naked-eye comets with small comas (i.e., high DC values). The observer slightly defocuses the comet and its comparison stars by the same amount until they appear the same size.

Modified-Out (Morris-O'Meara) method: Best for moderately condensed comets, the observer uses this method to defocus the comet's inner core first, until the brightness gradient between the inner and outer coma appears smooth. That image is then compared multiple times in the same night to stars that are defocused to match the comet's out-of-focus image.

Note that in all three methods, it's best to use comparison stars near the comet, or those in the same part of the sky and preferably at the same altitude as the comet.

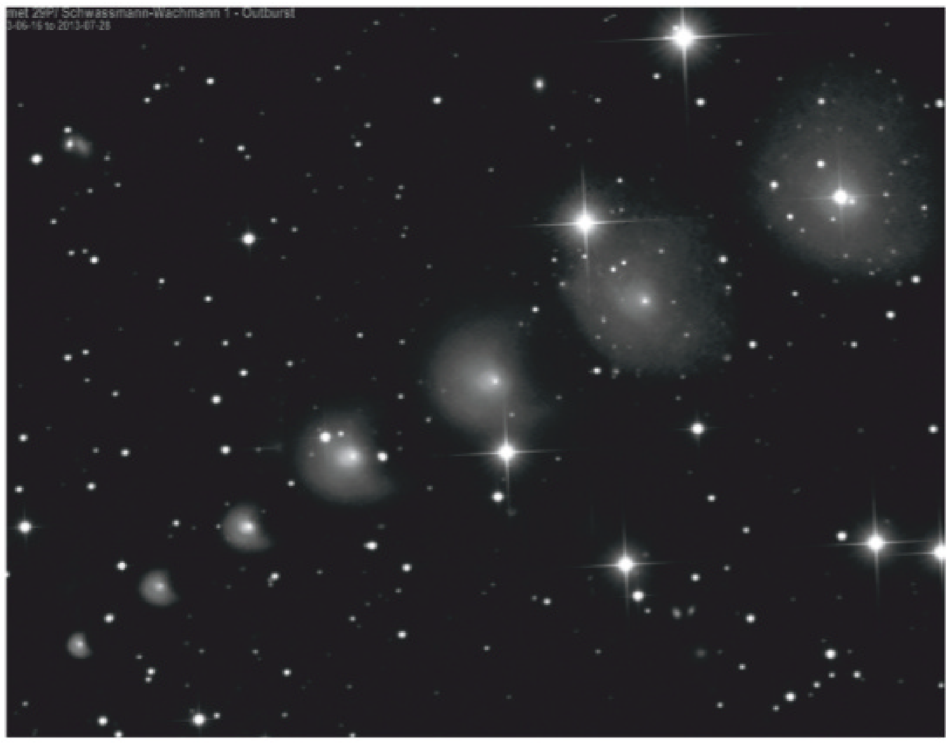
Comet tails and how to measure them

Comets have two principal types of tails: a dust tail (type II) and an ion tail (type I). When visible, dust tails are the easiest to observe, as dust efficiently reflects sunlight, which is primarily how comets shine. The dust tail originates from the comet's head and points away from the Sun, appearing brightest near the coma before gradually fading downwind. Dust tails can also dramatically curve, especially around the time of perihelion passage — or closest approach to the Sun — when dust freed from the nucleus follows the curved path of the comet's orbit.

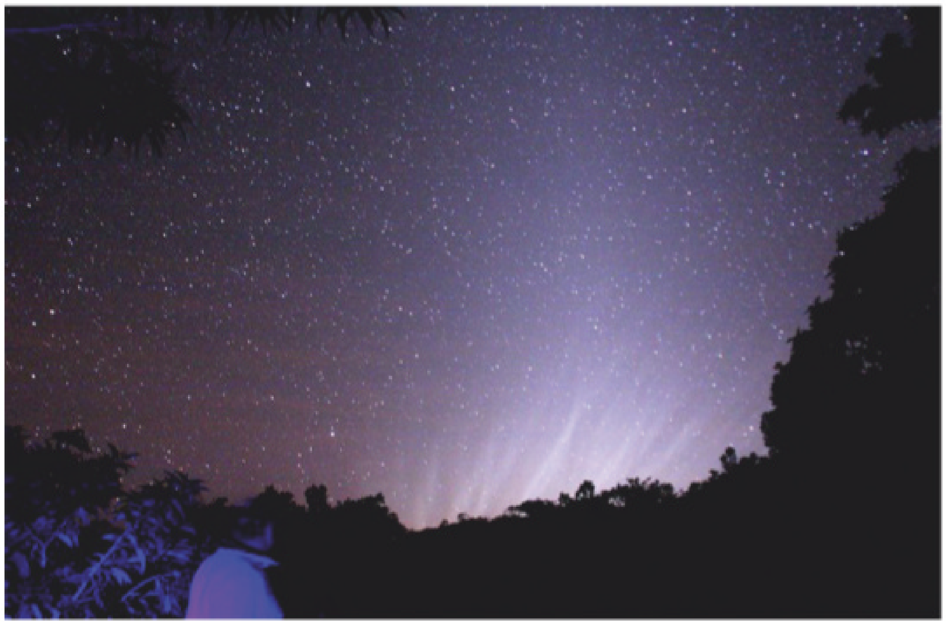
Another remarkable feature of dust tails are striations called synchrones. Though not well understood, they appear to be due to streams of debris that periodically erupt from the comet's nucleus as it rotates. Forces such as gravity, solar wind, and radiation pressure then act upon these streams, causing the delicate patterns we see. The tail of Comet C/2006 P1 (McNaught) was so resplendent with striations that the farthest tips were visible from parts of the Northern Hemisphere, despite the fact the comet's head and most of its tail were only visible from the Southern Hemisphere.

Comets can also change their appearance on a whim — that's what makes them so exciting to observe!

Some comets are bright enough for the cone cells in our eyes to detect their color, which can reveal whether the comet is richer in gas or dust. Yellow implies dust, while blue implies gas. Some comets also display green heads, a result of ultraviolet radiation breaking down diatomic carbon molecules (C_2), causing the head, and only the head, to fluoresce. The tails of dusty comets usually shine with a white or pale-yellow light, like straw under a setting Sun. When bright dust tails are seen close to the horizon, they can also take on a reddish hue due to dust or other contaminants in Earth's

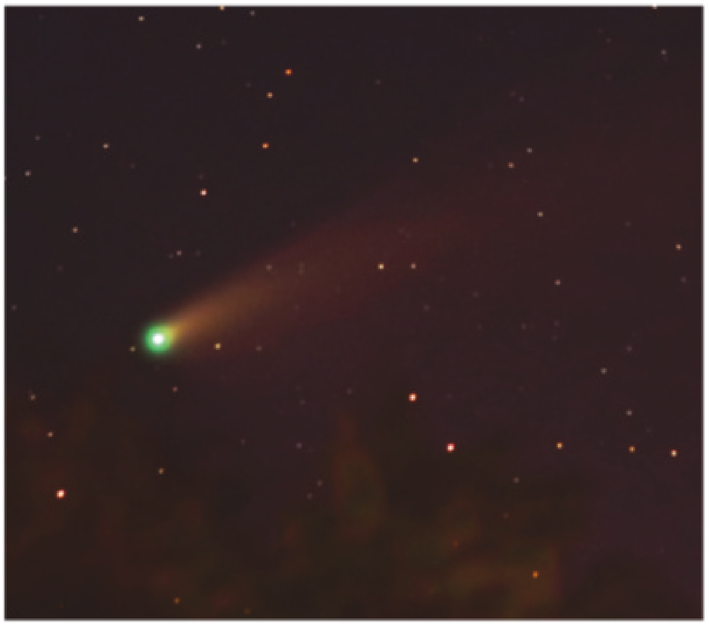


ABOVE: Comet 29P/ Schwassmann-Wachmann 1 undergoes an outstanding eruption in this composite of shots taken between June 16 and July 28, 2013. DAMIAN PEACH



BOTTOM ROW, CENTER LEFT: The broad, feathery dust tail of C/1995 O1 (Hale-Bopp) readily reflected sunlight, making it appear more obvious than the weakly glowing blue-hued ion tail in this April 4, 1997, image. E. KOLMHOFER, H. RAAB; JOHANNES-KEPLER-OBSERVATORY, LINZ, AUSTRIA (CC BY-SA 3.0)

BOTTOM ROW, CENTER RIGHT: Comets are full of surprises. This photo shows synchrones in C/2006 P1 (McNaught)'s dust tail, as seen projected against the zodiacal light from an altitude of 7,000 feet at the Mauna Loa volcano in Hawaii. STEPHEN JAMES O'MEARA

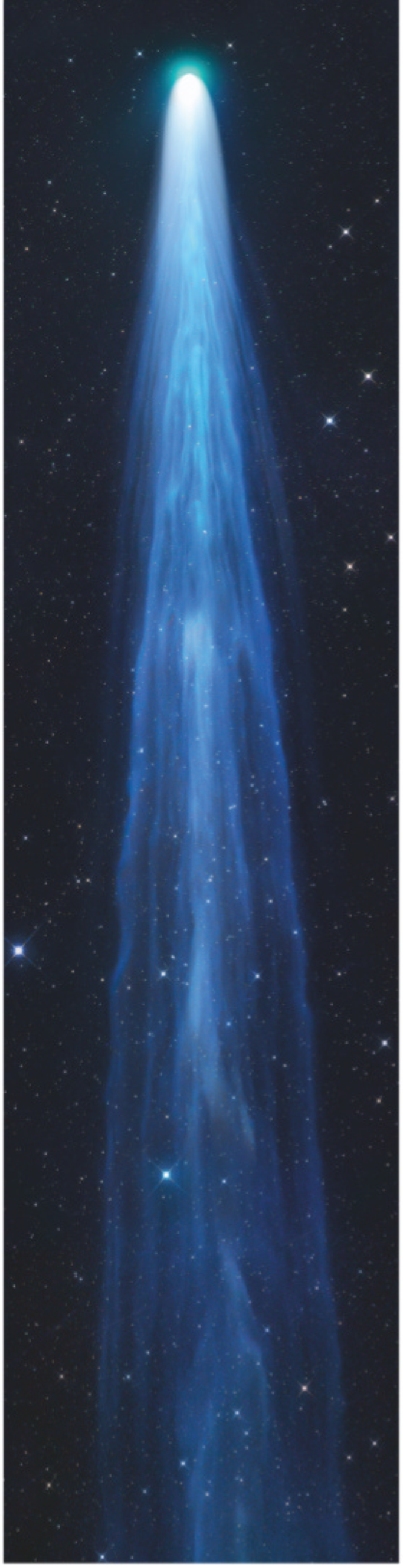


BOTTOM ROW, FARTHEST RIGHT: The gaseous green head of Comet C/2020 F3 (NEOWISE) is followed by a red tail, whose color is caused by dust in Earth's atmosphere due to the comet's low altitude. STEPHEN JAMES O'MEARA atmosphere, making them appear like bloody swords.

Ion tails, meanwhile, require greater effort to observe. They consist of electrically charged, glowing molecules, or ions, that follow the path of the solar wind almost exactly. The most common ion, CO^+ (carbon monoxide), absorbs sunlight and fluoresces at a wavelength of 420 nanometers, so ion tails tend to appear blue. Some observers, especially those with eyesight particularly sensitive to blue light, can see them clearly. English astronomer George Alcock was renowned for his observations of comet ion tails. Most observers, however, must work a bit to see them, especially when faint.

If an ion tail is present, use averted vision and sweep your telescope back and forth across the area of the sky behind the comet's head in the anti-solar direction. The same method can be used for naked-eye comets with a long ion tail — only in this case, sweep your eyes back and forth across the sky. The latter is the same technique an observer would use to bring out the zodiacal light against the background sky.

If a gaseous comet passes close to Earth, it can be an awe-inspiring sight. Such was the case with C/1996 B2 (Hyakutake), which came within 9.3 million miles (15 million kilometers) of Earth, or about 40 times the Earth-Moon distance. At its closest, Hyakutake's head swelled to greater than four Full Moon diameters, while its tail stretched more than halfway across the sky like a banner of pale light.



RIGHT: Comet C/2021 A1 (Leonard)'s tail shows intricate structure Dec. 27, 2021, just days after a disconnection event. GERALD RHEMANN

Ion tails often display hairlike streamers or braided (ropey) flows of gas. These tails can also appear frayed, with structures branching off from the main tail. Among the most remarkable phenomena associated with ion tails, however, is a disconnection event. These are triggered either by debris violently ejected from the comet's surface or by coronal mass ejections from the Sun slamming into the comet. Disconnection events occur when strong fluctuations in the solar wind pinch the magnetic field lines in the ion tail together, forming a knot that releases a powerful burst of energy strong enough to sever the tail, causing it to drift away. In some bright comets, knots and the resulting disconnection events can be observed with unaided eyes.

Finally, very rarely, comets can display anti-tails (type III) that appear when Earth passes through or close to the plane of a comet's orbit around the Sun.

BELOW LEFT: Gaseous Comet C/2020 F8 (SWAN) shines at 5th magnitude May 3, 2020. The glow in the left half of the image is zodiacal light. Only the comet's head and a 0.5°-long tail were dimly visible to the naked eye, while binoculars and averted vision brought out 1° of tail. In photos, the tail stretched nearly 10°. Such differences are common with gas tails. STEPHEN J. O'MEARA

BELOW RIGHT: Comet C/1996 B2 (Hyakutake) came so close to Earth that visual observers reported seeing colors in the tail. COURTESY OF WWW.CAPELLA-OBSERVATORY.COM

When this occurs, we see dust in the comet's orbit edge-on, causing it to appear like a sunward-pointing tail that lags behind the comet. Because anti-tails reflect sunlight, they are not difficult to see. Look for a long, slender lance (sometimes surrounded by an ellipsoidal envelope) or a triangular wedge fanning out from the comet's head. What we see depends on our viewing angle: The more needlelike the anti-tail, the closer Earth is to the comet's orbital plane.

Whatever tails are visible during your next observing session, you can determine their lengths and position angles by recording the positions of the comet's head and tail against the background stars, then plotting them on a star chart. Next, measure the length of the tail (usually in arcminutes or degrees) from where it comes off the comet's head to its tip. To determine position angle, use a protractor to measure the tail's orientation relative to the center of the coma, with north at 0°/360°, east at 90°, south at 180°, and west at 270°. For comets with broad dust tails, measure the two endpoints of the tail's width and record the extent; for example, a dust tail may sweep across the sky from a position angle of 45° to 90°.

Finer details

Let's now shift our attention to some of the more dynamic features comets can display. To observe them, you'll want to start by surveying the comet's head with your telescope at its highest effective magnification. While 50x per inch of aperture is comfortable, don't be afraid to push the power to 75x to 100x per inch of aperture, especially if you are using a high-quality scope under excellent atmospheric conditions.

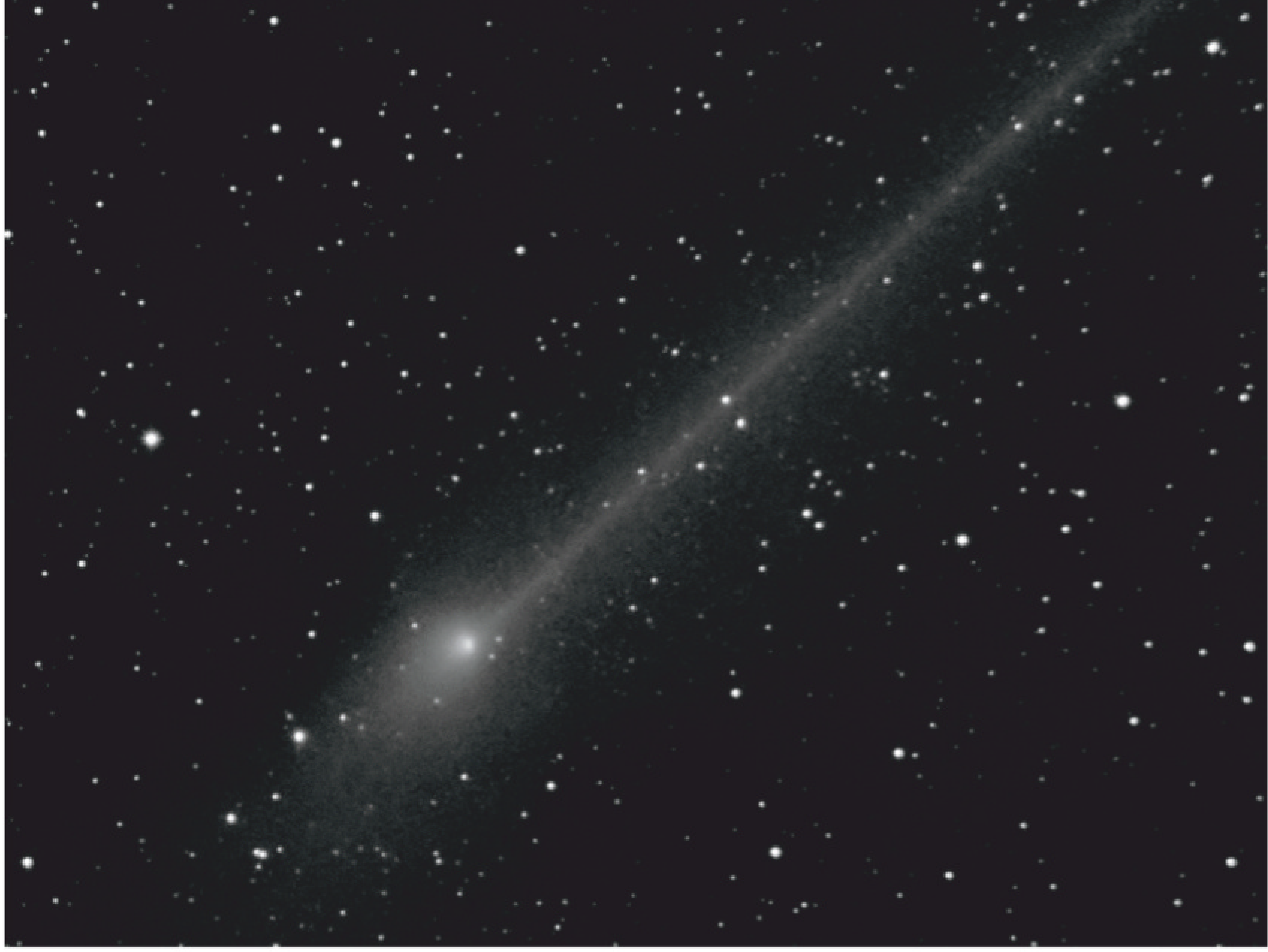
When visible, the pseudo-nucleus lies at the heart of a comet's coma. As the name implies, the pseudo-nucleus is not the comet's true nucleus, which, at generally only a few miles wide, is much too small and faint to resolve. The region around the pseudo-nucleus is where much of the most dynamic activity occurs. Watch for sudden surges in brightness, as they may signal the breakup of the nucleus, creating secondary nuclei. Such surges may also be caused by violent releases of dust-laden ice, especially as the comet nears the Sun. Some comet nuclei flare several times in a matter of days, which can add a new level of excitement to your session.

More common transient features are jets — high-velocity geyserlike eruptions emanating from the nucleus, which pierce the coma from various directions on its Sun-facing side. Jets are most intense near the pseudo-nucleus and gradually fade away at greater distances. Except for the brightest of comets, these features are generally of low contrast and require both patience and time to see. Typically, jets appear only slightly brighter than the surrounding coma, so the best approach is to use high power to diffuse the coma, which makes the jets stand out more prominently.

As the nucleus rotates and jets spiral outward, they can form a series of parabolic hoods (which look like bow waves that form at the front of a ship). Some of the most active comets also produce bold, sunward-facing jets that look more like broad plumes than rays or fans. These plumes fountain away from the pseudo-nucleus in sweeping gestures before curving back into the tail.

Don't forget: Comets are unpredictable! Who knows what other surprising features await? The only way to find out is to keep observing any comets you can. One of the greatest pleasures in comet observing is the thrill of witnessing the unexpected. As American physicist Leonard Susskind reminds us, "Unforeseen surprises are the rule in science, not the exception."

May the next bright comet dazzle us all.


Comet C/2011 L4 (PanSTARRS) displays a magnificent anti-tail May 26, 2013.
MALLORCASAINT AT ENGLISH WIKIPEDIA (CC BY-SA 3.0)

Stephen James O'Meara *has nearly 50 years of experience observing comets. His first comet sighting was of Comet C/1965 S1 (Ikeya-Seki). He began studying them in earnest at Harvard College Observatory in 1973, starting with Comet C/1973 E1 (Kohoutek).*

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

JANUARY 2023

Mars (the brighter orange object) remains in Taurus, changing up the usual appearance of the Bull's face. ALAN DYER

Long winter nights

Early winter sunsets offer nice evening views of the planets, starting with Mercury and Venus. Mercury quickly drops away, only to reappear in the morning sky before the end of the month. Venus is dazzling in the west and later in the month has a close encounter with Saturn, a stunning sight in small telescopes. Mars and Jupiter dominate the evening sky and the Red Planet is occulted by the Moon for observers in the southern U.S. Uranus and Neptune wander among fainter stars but are easy targets for binoculars or small scopes.

Let's begin on the evening of Jan. 1. **Mercury** is the first planet to set, within an hour of the Sun. Look with binoculars 6° due west of Venus 20 minutes after sunset for magnitude 1.1 Mercury to pop into view. At 6° high, you have about 30 minutes before it drops too low. By Jan. 3, Mercury fades to magnitude 2.2 and is very difficult to spot. It passes through inferior conjunction on the 7th, then reappears quickly in the morning sky; we will return to it later.

Venus stands 9° high in the southwest 20 minutes after sunset on Jan. 1. It dazzles in azure twilight at magnitude –3.9. The planet's angular elongation from the Sun increases from 17° to 24° during the month — a long, slow climb until it reaches greatest elongation in June.

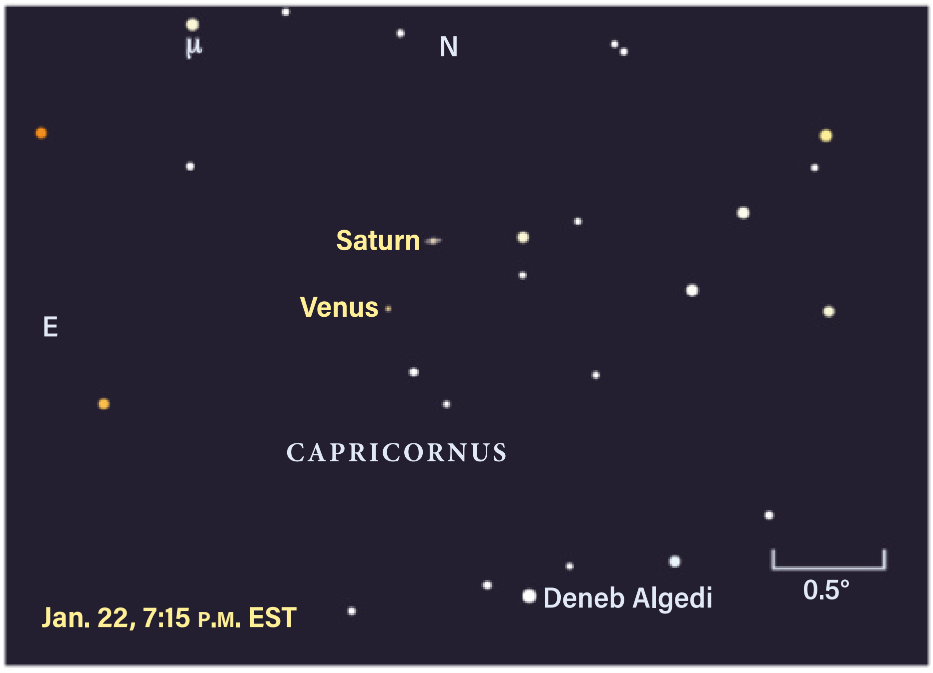
Venus spends most of the month in Capricornus and slides along the ecliptic to meet Saturn Jan. 22, when the two are separated by only 21". Check them out together in the same field of view in your telescope. A one-day-old Moon hangs 8° below them; spy this lovely view within half an hour of sunset, against the darkening sky. Venus and Saturn set nearly two hours after the Sun. The next day, a fatter crescent Moon is less than 7.5° east of Venus.

Venus crosses into Aquarius on the 24th. Through a telescope, it changes very slightly this month, growing from 10" to 11" across. Its gibbous phase slims from 96 percent to 91 percent lit between Jan. 1 and 31.

Saturn descends quickly into the twilight of January evenings. Its low altitude affects telescopic views. Catch it in the first week of January, when it is more than 20° high in the southwest shortly after sunset, glowing at magnitude 0.8. The rings in twilight are a wonderful sight and you have about an hour to observe them before the altitude really begins to affect the view. By mid-January, Saturn is less than 15° high an hour after sunset and likely resembles jelly pudding more than a ringed planet, but its conjunction with Venus is a must-see. By Jan. 31, Saturn is 14° east of the Sun and is quickly lost after sunset. It reaches conjunction with the Sun next month.

Neptune is a relatively easy binocular object high in the southwest once the sky is dark. Located in eastern Aquarius, the dim, distant planet shines at

Coming close



On Jan. 22, Venus and Saturn sit 21" apart. The planets' sizes are shown here relative to each other but do not represent their brightness compared to the background stars. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

VENUS and **SATURN** are just 21" apart Jan. 22, placing both in the same field of view.

magnitude 7.8 in a region devoid of bright stars. Instead, Jupiter 8° to its east is a useful guide.

In the first week of January, Neptune is located between two 7th-magnitude stars. If you've been following the planet, you know them. Find the easternmost pair of a parallelogram of four stars each about 1° apart, 5° northeast of Phi (ϕ) Aquarii. Neptune lies close to the northernmost star, passing 6' due south of it Jan. 11. By Jan. 20, Neptune sits 12' due east of the same star. The gap more than doubles by the end of January. A crescent Moon floats within 4° of Phi on Jan. 24, with Neptune some 5° above the Moon.

Attempt telescopic views early in the month and soon after dark, when the planet is over 30° high. The tiny disk spans 2", hard to observe unless conditions are ideal. Lower altitudes really affect its clarity.

Jupiter shines brightly in the southwest these winter evenings. It starts the month at magnitude –2.4 and slips by only 0.2 magnitude by Jan. 31. It treks eastward across the faint stars of Pisces the Fish. Watch for the lovely four-day-old crescent Moon to arrive Jan. 25, when the pair stand 3° apart.

Jupiter's disk spans 39" on Jan. 1 and shrinks by about 8 percent by Jan. 31. Start your observing in late twilight, when Jupiter's

— Continued on page 34

RISING MOON | Good librations

This simulated image shows how libration makes Luna's face look almost foreign this month. NASA'S SCIENTIFIC VISUALIZATION STUDIO

HAVE YOU EVER watched someone roll their head to stretch their neck? You don't see the back of their head, but you can view more than just their face. Our sister Luna performs a similar maneuver, called libration, with a 27-day period, revealing a total of 9 percent more than just her face to us: We also get a peek at the top, bottom, and sides. Binoculars are the best way to follow this motion, yet it is noticeable even to the discerning eye. We've hit the timing just right this month, as the 29.5-day illumination cycle is in sync with the roll.

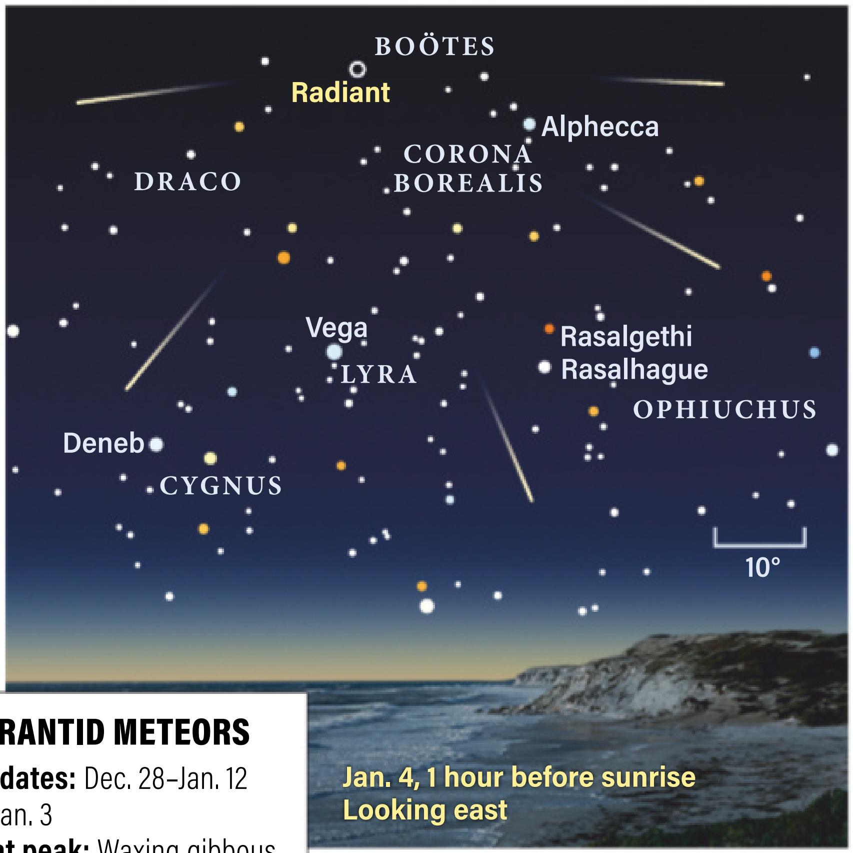
January opens with the east (right) edge prominently displayed, with Mare Crisium as far as it can get from the limb. As we approach Full Moon, the north seems to roll away, while down south, the pure white of the lunar highlands begins to blotch. The dense jumble of craters takes on gray, their bowls containing patches of lava that together make up Mare Australe. Notice how far up Tycho appears — six months from now, it will lie much closer to the southern limb. And check out the west, where the large gray oval of Grimaldi sits a bit more than once its own width from the edge, while the huge Oceanus Procellarum extends right to the limb.

Post Full phase, switch over to morning viewing (even past sunrise) to follow the libration with just a pair of binoculars. Grimaldi rolls away from the limb and each passing day reveals more and more of the white coastline of Procellarum in the northwest.

The next cycle opens with the waxing evening crescent on the 24th. Find the large patch of Mare Humboldtianum in the northeast; to its southwest lies the lovely oval-shaped Endymion. The striking pair Atlas and Hercules are further inward still. Mare Crisium is a fair distance in, letting the dark patches of Mare Smythii and Marginis highlight the limb. The whole sequence now nearly repeats, starting two days earlier.

METEOR WATCH | Catch a few falling stars

Quadrantid meteor shower



Jan. 4, 1 hour before sunrise
Looking east

The Quadrantids' radiant is highest before dawn. Its position will be much the same whether you observe on the 3rd or 4th.

QUADRANTID METEORS

Active dates: Dec. 28–Jan. 12
Peak: Jan. 3
Moon at peak: Waxing gibbous
Maximum rate at peak: 110 meteors/hour

THIS ANNUAL WINTER SHOWER is a regular for observers, but early January's Full Moon strongly affects viewing this year. The Quadrantids, named after a defunct constellation in what is now northern Boötes, are active from Dec. 28 to Jan. 12, peaking late on Jan. 3 in the U.S. Full Moon occurs on the 6th. Only brighter members of the shower, which normally generates about 40 meteors per hour before dawn, will be visible. Though this year's predicted zenithal hourly rate is 110, with the Moon around, you'll see far fewer.

The radiant rises after midnight, offering a steady increase in rate as dawn approaches. Brace against those cold winter temperatures as you enjoy your morning cuppa outside and gaze upward. You might catch one of the rare bright ones. The Quadrantids are associated with the periodic comet 96P/Machholz and the minor planet 2003 EH_1.

STAR DOME

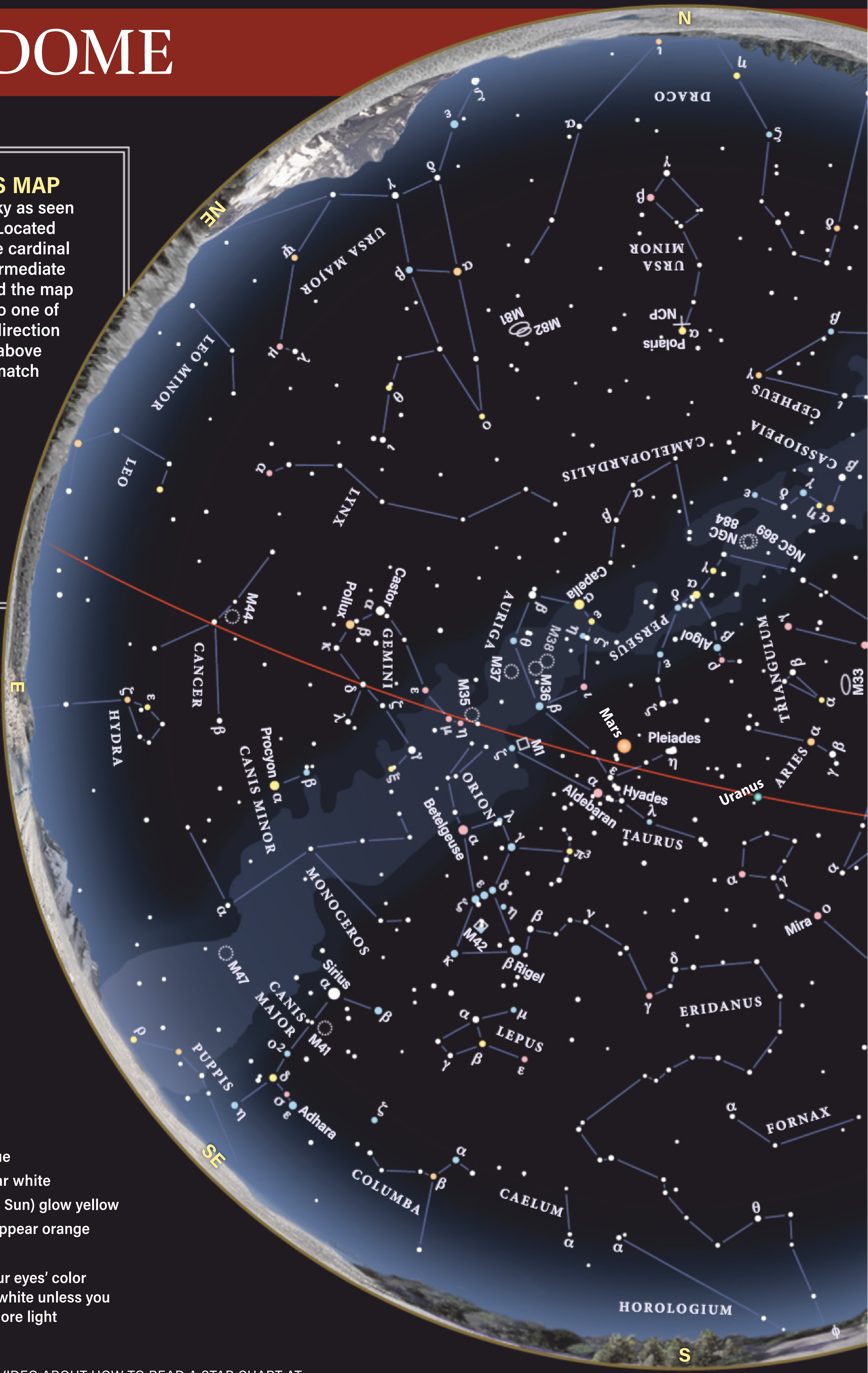
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. January 1
8 P.M. January 15
7 P.M. January 31

Planets are shown at midmonth



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LEO MINOR
LEO
LYNX
Castor
Pollux
GEMINI
Capella
AURIGA
M37
M38
M36
M35
PERSEUS
Algol
TRIANGULUM
M33
ARIES
M44
CANCER
HYDRA
Mars
Pleiades
Uranus
Hyades
Aldebaran
TAURUS
M1
ORION
Betelgeuse
Procyon
CANIS MINOR
MONOCEROS
M42
Rigel
Mira
ERIDANUS
M47
Sirius
CANIS MAJOR
M41
LEPUS
PUPPIS
Adhara
COLUMBA
CAELUM
FORNAX
HOROLOGIUM

MAP SYMBOLS

- ◌ Open cluster
- ⊕ Globular cluster
- ☐ Diffuse nebula
- ⌖ Planetary nebula
- ⬭ Galaxy

STAR MAGNITUDES

● Sirius

● 0.0 • 3.0

● 1.0 • 4.0

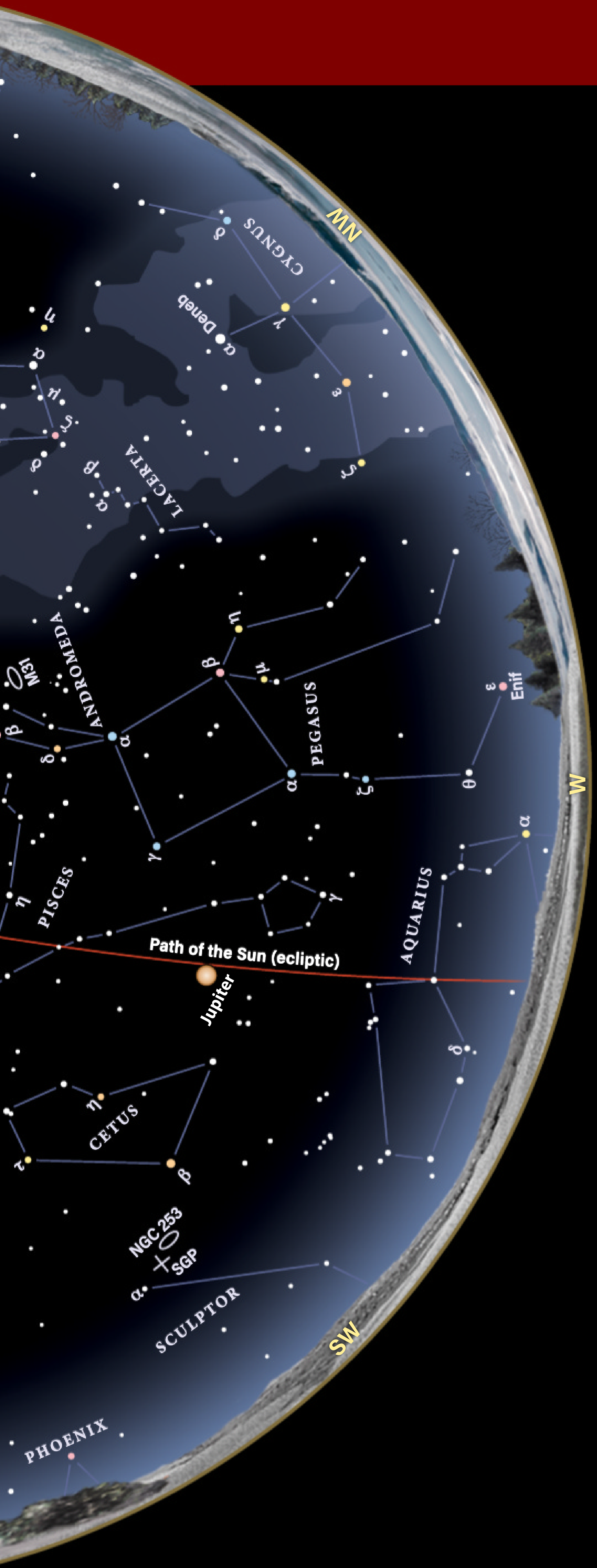
• 2.0 · 5.0

STAR COLORS

A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**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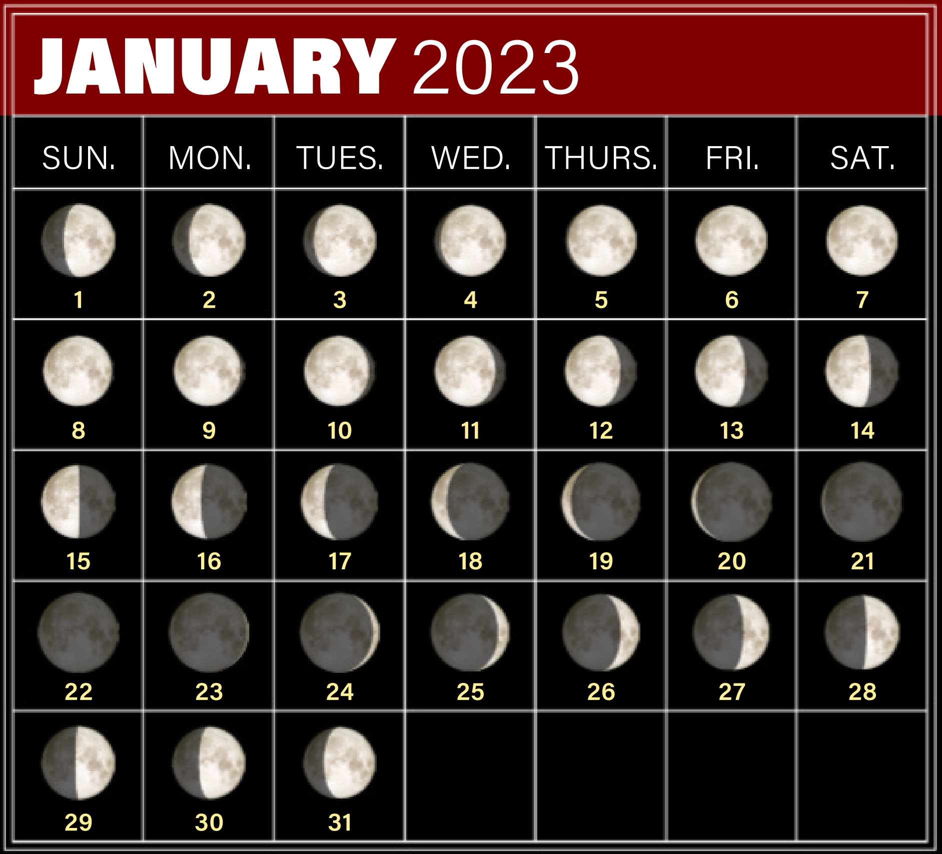
JANUARY 2023



SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 The Moon passes 0.7° north of Uranus, 5 P.M. EST

3 The Moon passes 0.5° south of Mars, 3 P.M. EST

Quadrantid meteor shower peaks

4 Earth is at perihelion (91.4 million miles from the Sun), 11 A.M. EST

6 Full Moon occurs at 6:08 P.M. EST

7 Mercury is in inferior conjunction, 8 A.M. EST

8 The Moon is at apogee (252,562 miles from Earth), 4:19 A.M. EST

Asteroid Pallas is at opposition, 2 P.M. EST

12 Mars is stationary, 3 P.M. EST

14 Last Quarter Moon occurs at 9:10 P.M. EST

18 Mercury is stationary, 7 A.M. EST

Pluto is in conjunction with the Sun, 10 A.M. EST

20 The Moon passes 7° south of Mercury, 3 A.M. EST

Jupiter is at perihelion (460 million miles from the Sun), 7 A.M. EST

21 New Moon occurs at 3:53 P.M. EST

The Moon is at perigee (221,562 miles from Earth), 3:57 P.M. EST

22 Venus passes 0.4° south of Saturn, 3 P.M. EST

Uranus is stationary, 10 P.M. EST

23 The Moon passes 4° south of Saturn, 2 A.M. EST

The Moon passes 3° south of Venus, 3 A.M. EST

25 The Moon passes 3° south of Neptune, 1 A.M. EST

The Moon passes 1.8° south of Jupiter, 9 P.M. EST

26 Asteroid Hebe is at opposition, 4 A.M. EST

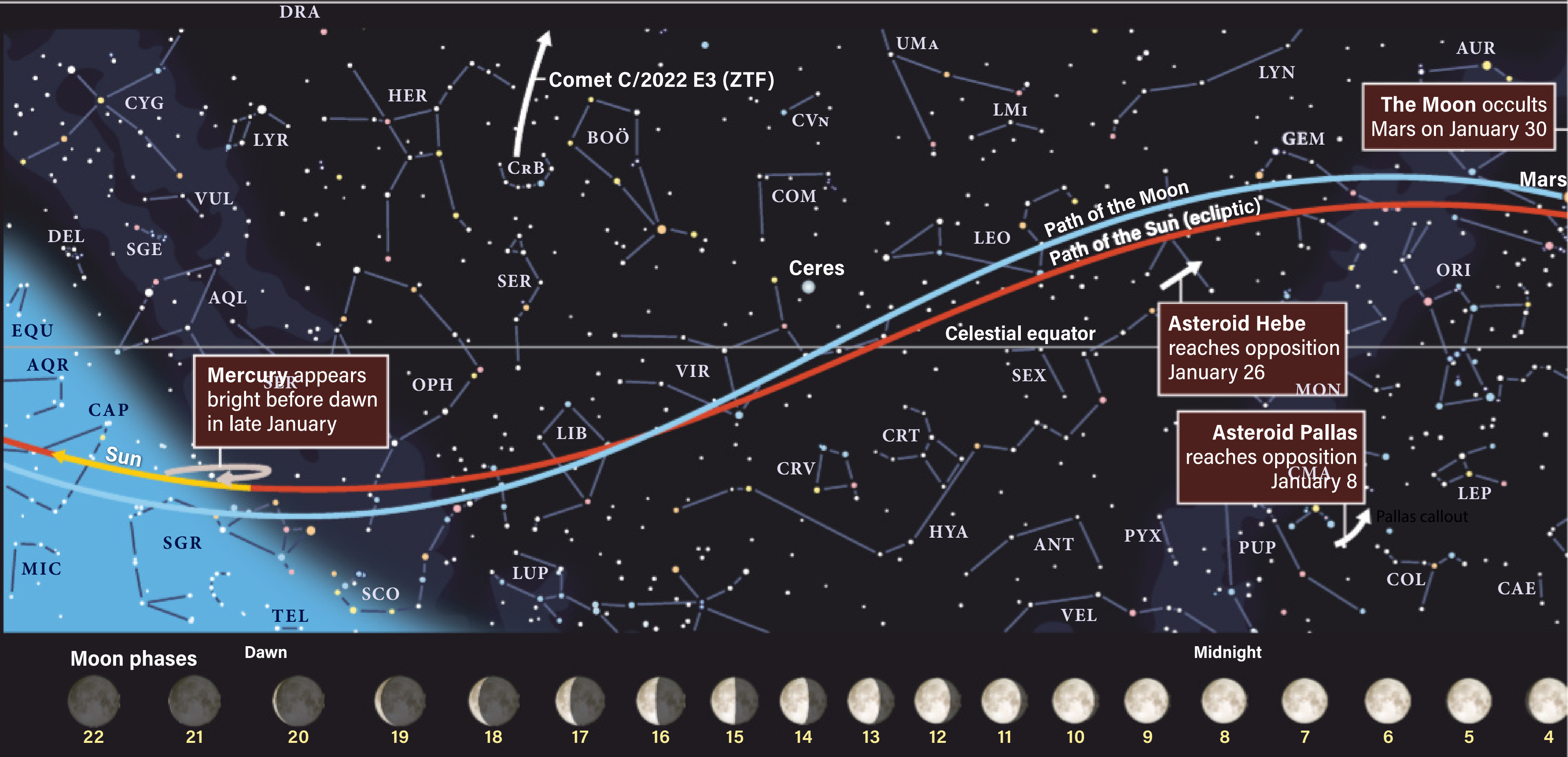
28 First Quarter Moon occurs at 10:19 A.M. EST

The Moon passes 0.9° north of Uranus, 11 P.M. EST

30 Mercury is at greatest western elongation (25°), 1 A.M. EST

The Moon passes 0.1° south of Mars, 11 P.M. EST

PATHS OF THE PLANETS


DRA
CYG
LYR
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CVN
UMA
LMI
LYN
AUR
GEM
VUL
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SGE
AQL
EQU
SER
COM
Ceres
LEO
Path of the Moon
Path of the Sun (ecliptic)
Mars
ORI
Celestial equator
AQR
CAP
SER
OPH
VIR
SEX
MON
Sun
LIB
CRT
CRV
CMA
LEP
Pallas callout
SGR
MIC
HYA
ANT
PYX
PUP
COL
CAE
LUP
SCO
TEL
VEL
Moon phases
Dawn
Midnight
22
21
20
19
18
17
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5
4

Comet C/2022 E3 (ZTF)

The Moon occults Mars on January 30

Mercury appears bright before dawn in late January

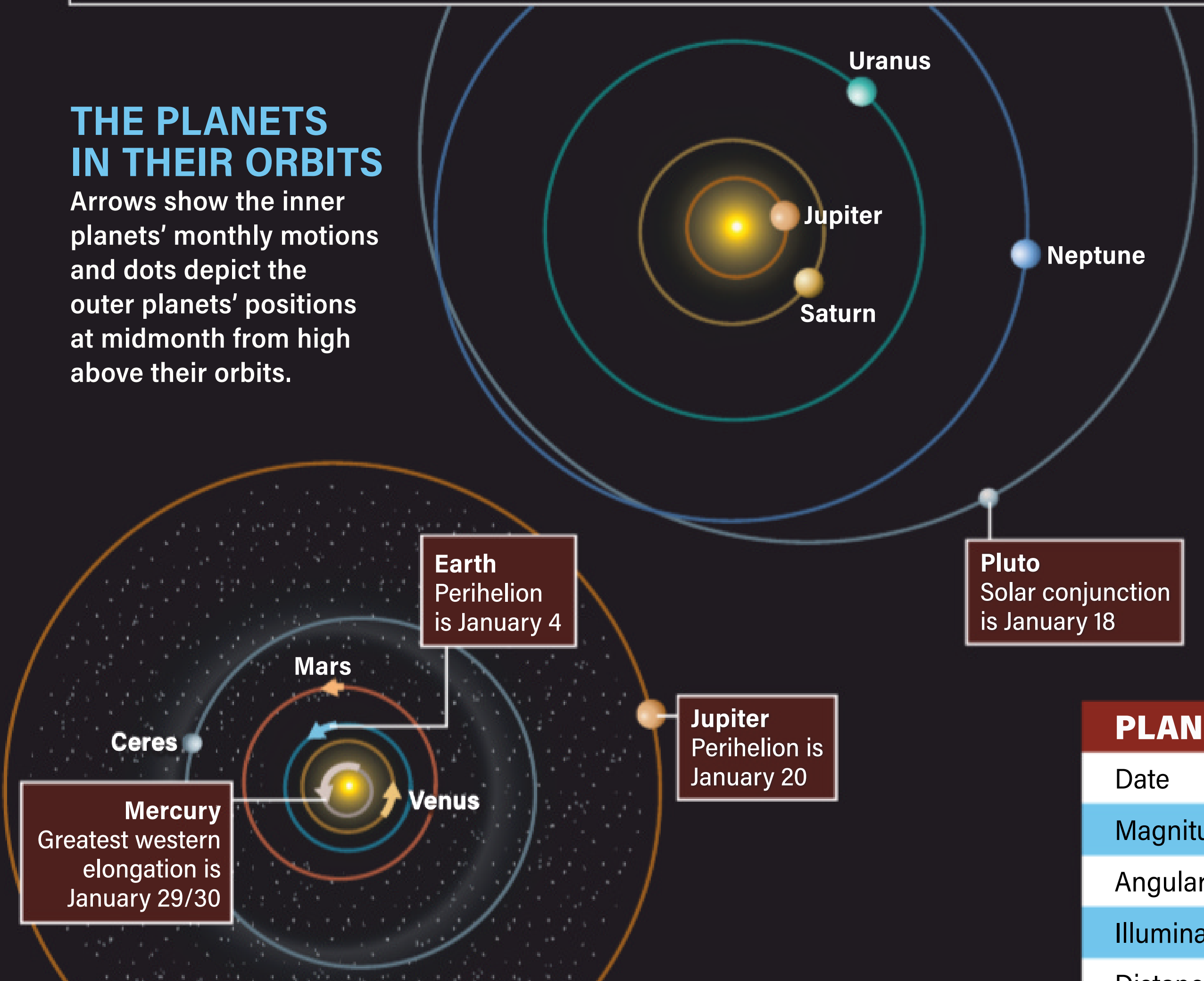
Asteroid Hebe reaches opposition January 26

Asteroid Pallas reaches opposition January 8

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.


Uranus
Jupiter
Saturn
Neptune
Mars
Ceres
Venus

Pluto Solar conjunction is January 18

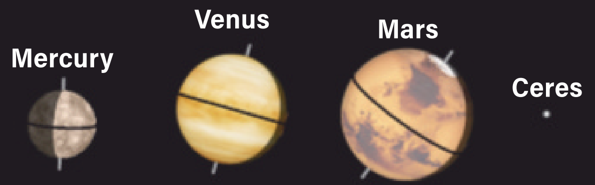
Earth Perihelion is January 4

Jupiter Perihelion is January 20

Mercury Greatest western elongation is January 29/30

THE PLANETS IN THE SKY

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.

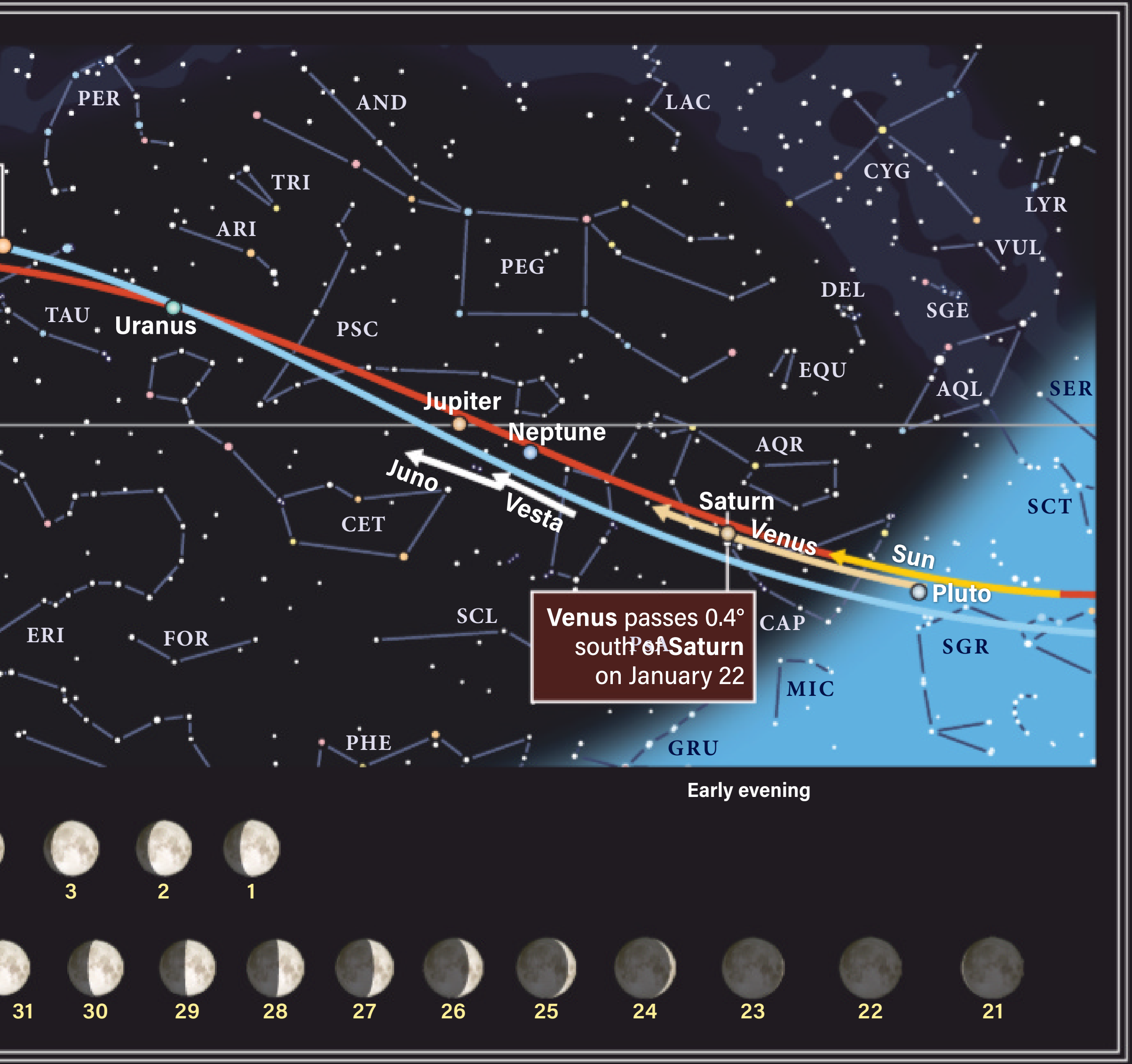

Mercury
Venus
Mars
Ceres

PLANETS	MERCURY	VENUS
Date	Jan. 31	Jan. 15
Magnitude	–0.1	–3.9
Angular size	6.6"	10.7"
Illumination	64%	94%
Distance (AU) from Earth	1.013	1.563
Distance (AU) from Sun	0.433	0.727
Right ascension (2000.0)	19h07.2m	21h10.1m
Declination (2000.0)	–21°40'	–17°58'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

JULY 2021

JANUARY 2023


PER
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Uranus
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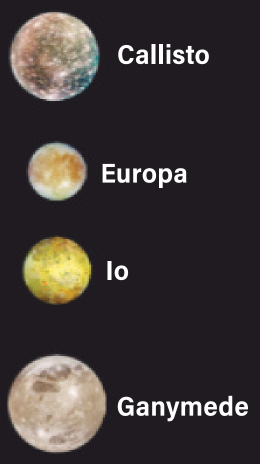
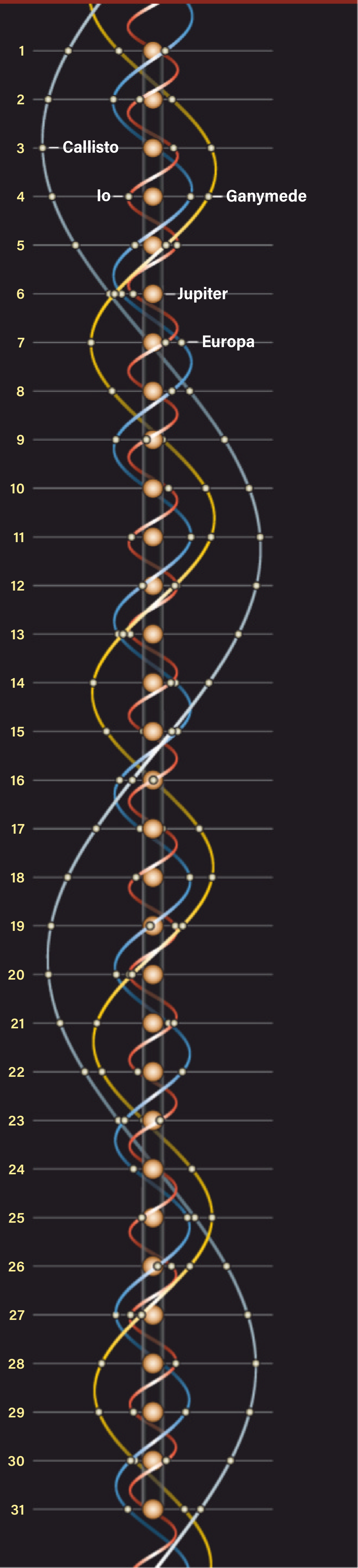
Jupiter
Neptune
AQR
Juno
Vesta
Saturn
Venus
SCT
CET
Sun
Pluto
ERI
FOR
SCL
CAP
SGR
MIC
PHE
GRU
Early evening
3
2
1
31
30
29
28
27
26
25
24
23
22
21

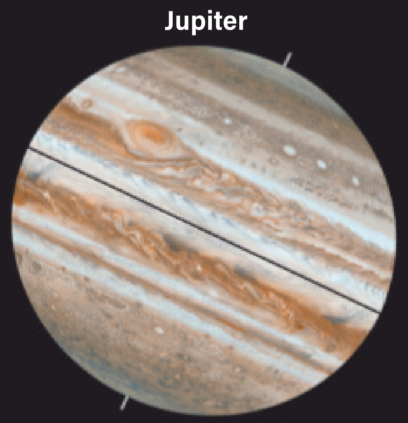
Venus passes 0.4° south of Saturn on January 22

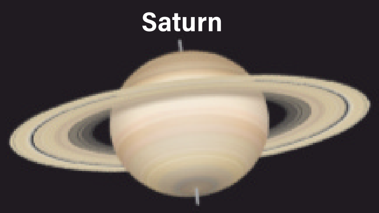

Callisto
Europa
Io
Ganymede

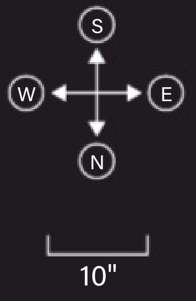
JUPITER'S MOONS

Dots display positions of Galilean satellites at 10 P.M. EST on the date shown. South is at the top to match the view through a telescope.





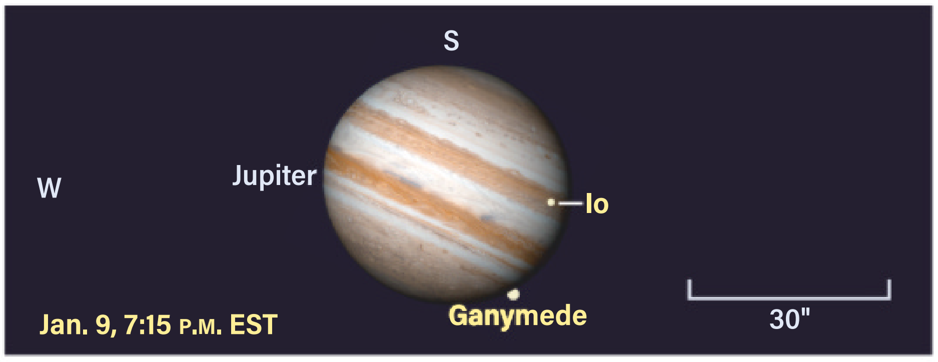




MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15
–0.8	8.1	–2.3	0.8	5.7	7.8	15.1
12.8"	0.6"	37.7"	15.6"	3.7"	2.2"	0.1"
95%	97%	99%	100%	100%	100%	100%
0.733	2.064	5.225	10.677	19.303	30.413	35.668
1.581	2.552	4.951	9.832	19.668	29.912	34.687
4h22.2m	12h40.2m	0h12.3m	21h45.3m	2h49.2m	23h35.5m	20h01.5m
24°24'	9°52'	–0°01'	–14°50'	15°54'	–3°56'	–22°49'

— Continued from page 29

Quick succession



The Galilean moons are busy this month. On Jan. 9, Io begins a transit just minutes before Ganymede starts to reappear from behind Jupiter. Outside this field of view, Callisto lies east of Jupiter and Europa to the west.

brilliance is tempered by the background sky. The two dark equatorial belts straddling the equator first come into view, with more subtle features following with patient observing.

Io undergoes an occultation the evening of Jan. 1, opening a month of fine events. The moon disappears behind the western limb of Jupiter around 7:45 P.M. EST. The following evening at the same time, Io has made half an orbit and its shadow is in the middle of transiting Jupiter's face. The shadow leaves just before 8:40 P.M. EST.

West Coast observers can see Callisto partially occulted by Jupiter's northern limb Jan. 7, beginning around 8:30 P.M. PST and lasting nearly an hour. The event repeats Jan. 24, this time for the eastern half of the U.S., starting around 7:10 P.M. EST.

Two events occur Jan. 9, when Io starts a transit around 7:05 P.M. EST. Ganymede slips out from behind Jupiter shortly after, around 7:09 P.M. EST. The giant moon takes about five minutes to fully reappear.

Europa begins a transit on Jan. 19 at about 7:45 P.M. EST. Its shadow doesn't appear until just after 10:10 P.M. EST, less than 10 minutes before Europa itself leaves the opposite side of the disk. The Royal Astronomical Society of Canada's 2023 *Observer's Handbook* lists other events throughout the month.

Uranus lies in sparse southern Aries, an easy binocular target at magnitude 5.7. Look for a pair of 5th-magnitude stars, Sigma (σ) and Pi (π) Arietis, creating a 2.5°-long north-south line. Uranus is a little less than midway between these stars on Jan. 1, a bit closer to Sigma. The planet drifts slightly west of a line joining the stars throughout January. Uranus gradually slows to a stationary point Jan. 22, 1° northwest of Sigma Arietis.

The planet is visible all evening and sets soon after 1 A.M. local time by January's end. Through a telescope, its 4"-wide disk appears blue. On Jan. 28/29, look for Uranus close to the gibbous Moon in the late evening. Uranus stands only 0.5° due south of the Moon's southern limb soon after midnight on the 29th for East Coast observers (still the 28th in all other U.S. time zones). Earlier in the evening, Uranus is southeast of Luna's southern limb.

Mars is a spectacular object in Taurus, shining at magnitude –1.2 on Jan. 1. That night, the Red Planet is nearly 70° high around 8:30 P.M. local time.

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (southwest)
Venus (west)
Mars (east)
Jupiter (southwest)
Saturn (southwest)
Uranus (southeast)
Neptune (southwest)

MIDNIGHT
Mars (west)
Uranus (west)

MORNING SKY
Mercury (southeast)

COMET SEARCH | Sky trip!

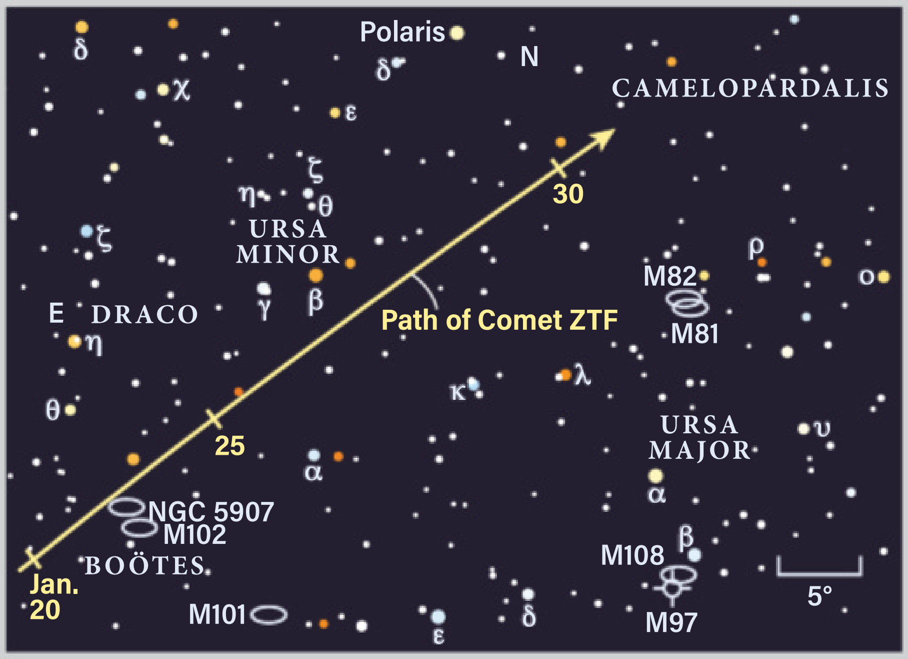
LET'S GET the most from the bright binocular comet C/2022 E3 (ZTF) during its speedy two-month flight. Barring a welcome surprise, ZTF will be the best of the year. South of the equator, observers instead get 12 months of the stalwart C/2017 K2 (PanSTARRS) skirting their pole.

ZTF brightens rapidly from 9th magnitude into binocular range while accelerating toward perihelion on the 12th. Despite the Full Moon mid-month, try to catch the 6th-magnitude fuzzball from the suburbs. By the 18th, early risers can enjoy ZTF high in the northeast without interference from the waning crescent Moon. Those preferring to stay up until 2 A.M. can observe before the Moon rises two nights earlier, but know the comet might be fighting trees and buildings.

Imagers on the morning of the 22nd will enjoy ZTF's green glow with M102 and the Splinter Galaxy (NGC 5907) only 3° away. Visual observers, watch the wedge-shaped tail suddenly narrow into a spike on the 24th, then quickly spread back out in only 48 hours as Earth punches through ZTF's orbital plane at nearly a right angle. Geometry favors us with a short sunward-pointing anti-tail, which could be blue if ZTF produces enough gas. This climax might last only one night, so be prepared to jump into action.

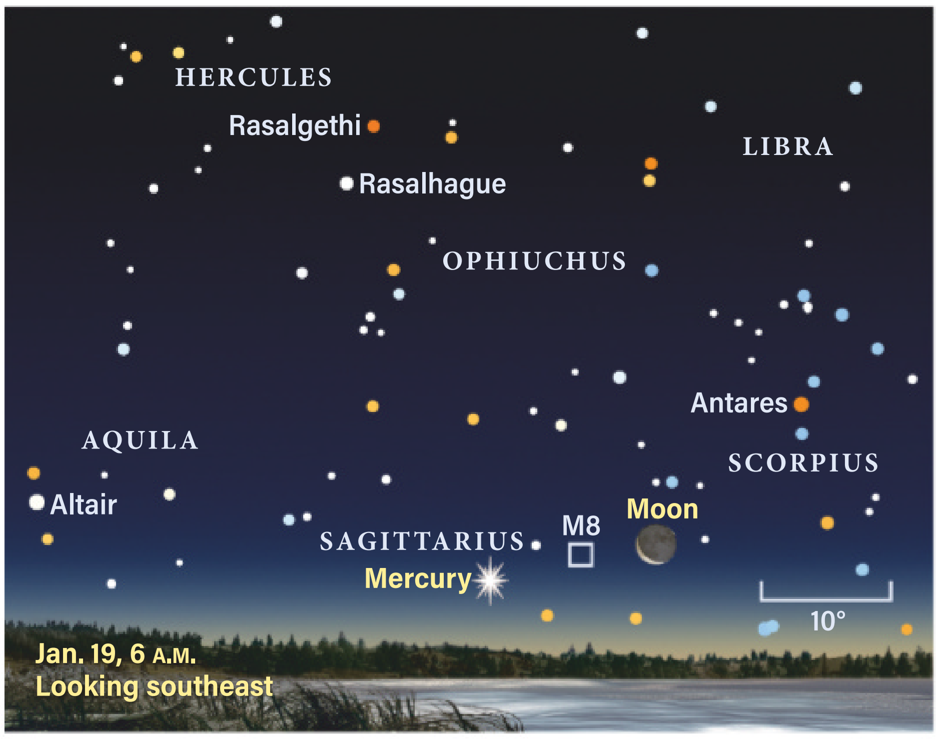
ZTF is closest to Earth at month's end, potentially glowing as bright as 5th magnitude not far from Polaris. Its rapid motion of 12" per minute forces short exposures to keep details sharp. Dedicated astroimagers could make a two-week panoramic composite.

Comet C/2022 E3 (ZTF)



Comet ZTF covers vast swaths of sky each night later this month. Visit our website for finder charts to locate and track the comet in early to mid-January.

Morning Mercury



Catch Mercury near the crescent Moon in the morning sky Jan. 19, with the Lagoon Nebula (M8) between them, visible with binoculars or a telescope.

Mars lies about 9° east of the Pleiades star cluster (M45) and 8.5° north-northwest of Aldebaran. The planet slows to a halt Jan. 12, ending its retrograde motion and resuming an easterly trek, reaching 10° east of M45 by Jan. 31, when Mars sets just before 3:30 A.M.

Watch Mars and the waxing gibbous Moon close in on each other Jan. 30. For northern states, the two lie very close, just a few arcminutes between them. From locations south of about 37° north latitude, the Moon occults Mars; the time depends on your location. From Miami, Mars is occulted at 12:38 A.M. EST on Jan. 31 and reappears at 1:27 A.M. EST. In Dallas, Mars disappears at 11:18 P.M. CST on Jan. 30 and reappears nearly four minutes after local midnight on the 31st. Los Angeles observers see Mars vanish at 8:36 P.M. PST and reappear at 9:29 P.M. PST. Mars takes nearly a minute to disappear and reappear, so prepare your scope 30 minutes before the event and begin observing at least five minutes before the occultation is set to start.

Through a telescope, Mars is well past its best. On Jan. 1, it spans 15" and is 97 percent lit, large enough for moderate telescopes to see surface features. By the end of January, it shrinks to 11" wide and surface features become more challenging. The phase slims to 92 percent. Mars also fades to magnitude –0.3.

At about 9 P.M. Central time, the following features are visible (for the mid-U.S.): Jan. 1: Sinus Meridiani with Syrtis Major leaving the disk; Jan. 10: Syrtis Major, Hellas, and Elysium; Jan. 23: Olympus Mons, Tharsis Ridge, and Mare Sirenum; Jan. 30: Tharsis, Valles Marineris, Solis Lacus, and Mare Erythraeum. Features and their positions vary depending on the time and your location.

Mercury skips into the morning sky after its Jan. 7 inferior conjunction and quickly attains visibility by mid-month. It reaches magnitude 0.6 on the morning of Jan. 17 and stands 5° high in the southeast 45 minutes before sunrise.

Look for Mercury nearly 15° left (east) of the waning crescent Moon on Jan. 19. The magnitude 0.4 planet is only 1° high at 6:00 A.M. local time; the Moon is four times higher, so use it to spot the innermost planet. You'll need a clear southeastern horizon. The Lagoon Nebula (M8) lies roughly midway between the two; binoculars should net it before the sky brightens too much.

By Jan. 25, Mercury reaches magnitude 0 and stands 8.5° high in eastern Sagittarius around 6:45 A.M. local time. On Jan. 30, it glows at magnitude –0.1 some 7' northeast of 4th-magnitude Omicron (ο) Sagittarii. This is Mercury's greatest elongation west, 25° from the Sun. On the 31st, Mercury stands 40.5' due south of Pi Sagittarii and is 4° high a full hour before sunrise.

Earth reaches perihelion, the closest point to the Sun in its orbit, Jan. 4 at 11:17 A.M. EST, when we stand 91,402,515 miles from our star.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

GET DAILY UPDATES ON YOUR NIGHT SKY AT
www.Astronomy.com/skythisweek.

LOCATING ASTEROIDS

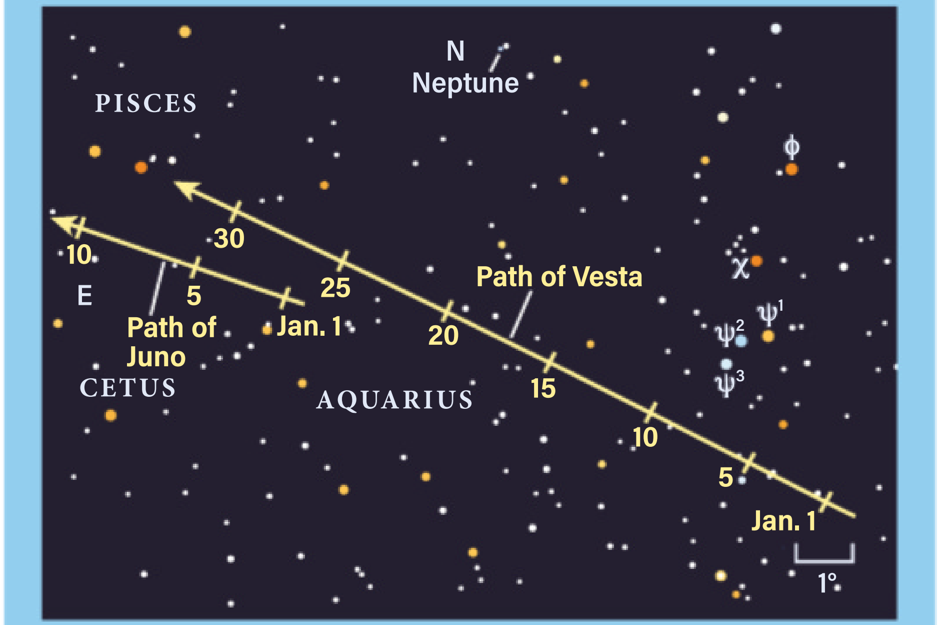
Vesta swims past Neptune

MUCH EASIER TO FIND than last month, asteroid 4 Vesta passes the standout broad triplet of ψ^1, ψ^2, and ψ^3 Aquarii. The Greek letter psi (ψ) looks nearly the same as Neptune's planetary symbol because in Greek, the god's name is Poseidon. And, by coincidence, the blue ice giant is only some 5° north of Vesta's path.

We're a fair distance from the plane of the Milky Way here, so the background star fields contain a varied smattering that is straightforward to navigate. In just an hour at the eyepiece on the 4th, you can watch Vesta separate from a pair of stars straddling its path. Consider also tracking down nearby 3 Juno, which leaves the scene early on. And avoid Jan. 25, when the Moon is nearby.

In yet another appulse, Uranus hosts 10th-magnitude 27 Euterpe 1° to its south during the first week of January. A box of stars acts as a great reference to reveal the night-to-night shift of that asteroid.

Sharing a swim



Vesta and Juno skim just south and east of Neptune (whose position is shown on the 15th) this month. Jupiter sits slightly northeast of this field.

COMET NEOWISE (C/2020 F3)

GREAT COMETS

Take a trip down memory lane to revisit the most spectacular comets of the past half-century. BY MICHAEL E. BAKICH

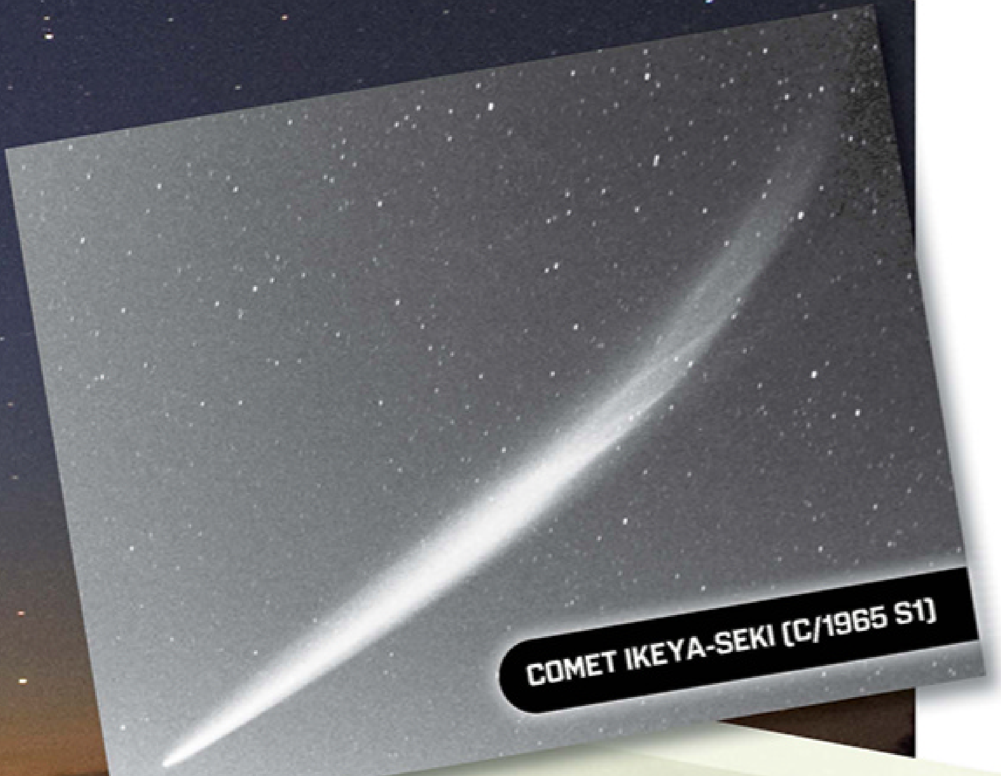
THE WORLD OF COMETS

GREAT COMETS ARE FIXTURES throughout astronomical history. They pop up unexpectedly and can change the way people see the skies, creating unforgettable experiences that can inspire and live on in our collective memory. Typically, astronomers denote a comet as "great" if it reaches easy naked-eye visibility. It helps if the comet can be seen for a long time, as was the case with Comet Hale-Bopp (C/1995 O1), but even a comet only visible for a few days can be great if it's bright enough. The most recent great comet was Comet McNaught (C/2006 P1).

Readers familiar with my stories know that I love lists. So, when asked to choose the greatest comets in recent history, I thought, "Oh, what fun that will be!" The big question was how far back to go. Initially, I decided to start when *Astronomy* began, in 1973. After more thought, however, there were two comets I simply couldn't leave off the list. I think you'll agree because the first was one of the most spectacular celestial sights ever seen.

If you're old enough to have observed any of the following comets' visits, you'll remember exactly where you were when they blazed brightest in the sky. So, let's take a trip down memory lane — and keep hope alive that we'll all be treated to another great comet very soon.

COMET NEOWISE (C/2020 F3) • Comet NEOWISE gracefully arcs though twilight in December 2020. GERALD RHEMANN



COMET IKEYA-SEKI (C/1965 S1) • Comet Ikeya-Seki shows off a twisted, ropey structure in its 30°-long tail in this Oct. 30, 1965, shot. JAMES W. YOUNG (TMO/JPL/NASA)

Fig. 2
COMET BENNETT (C/1969 Y1)

COMET BENNETT (C/1969 Y1) • This two-minute exposure of Comet Bennett was taken from Hamburg Observatory and highlights a visible kink in the comet's ion tail. K. LUBECK/L.F. BURLAGA, J. RAHE, B.D. DONN, B. D., & M. NEUGEBAUER

# of our TIME

Comet Ikeya-Seki (C/1965 S1)

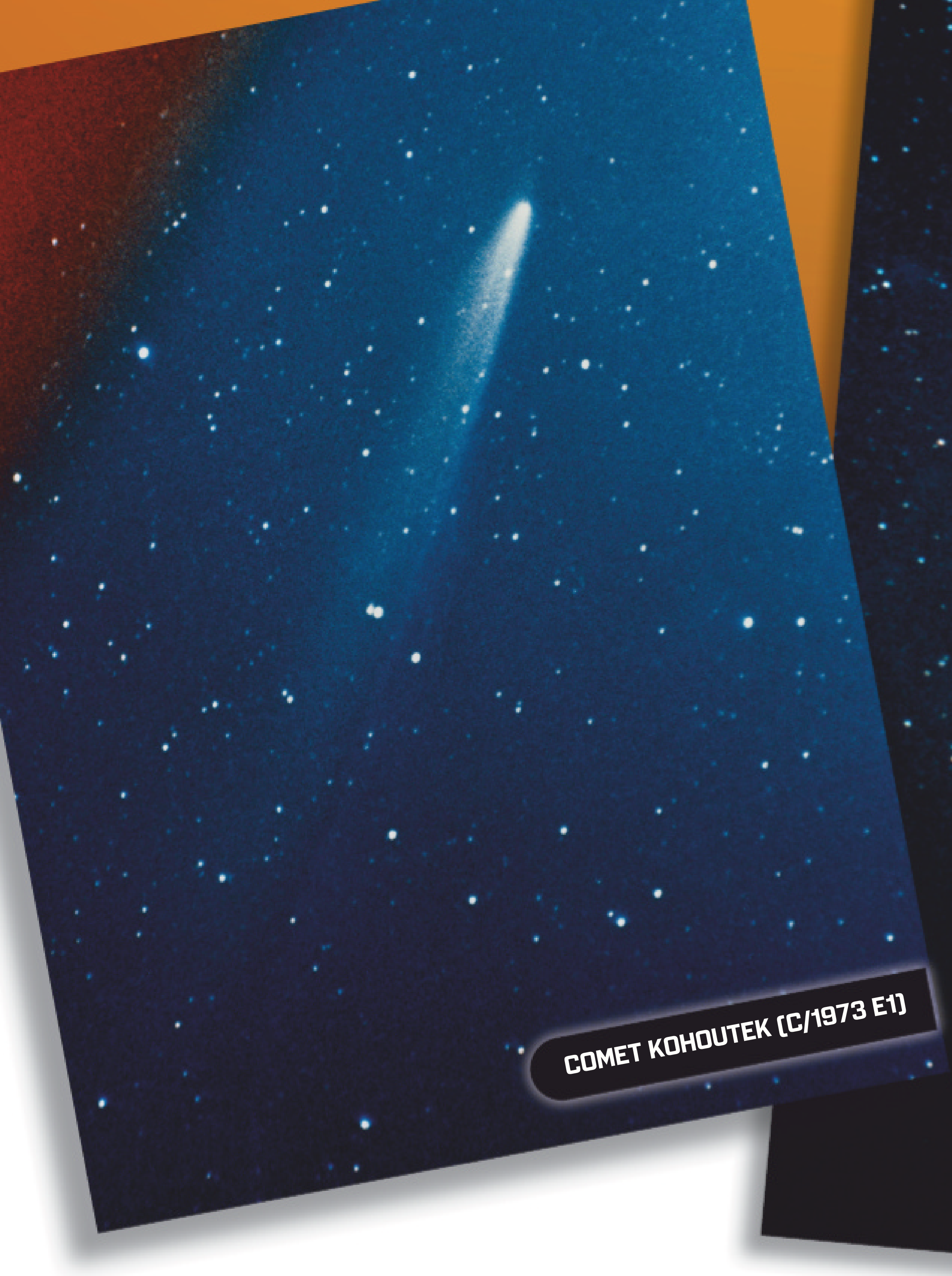
On Sept. 18, 1965, amateur astronomer Kaoru Ikeya and professional astronomer Tsutomu Seki independently discovered what became the greatest comet of the century, Ikeya-Seki. When researchers calculated its orbit, they found it was a sungrazer — a comet that passes extremely close to the Sun. Small sungrazers usually evaporate or are torn apart by tidal forces. Large ones, however, can not only survive, but might also become extremely bright. Observers hoped Ikeya-Seki would fall into the latter category.

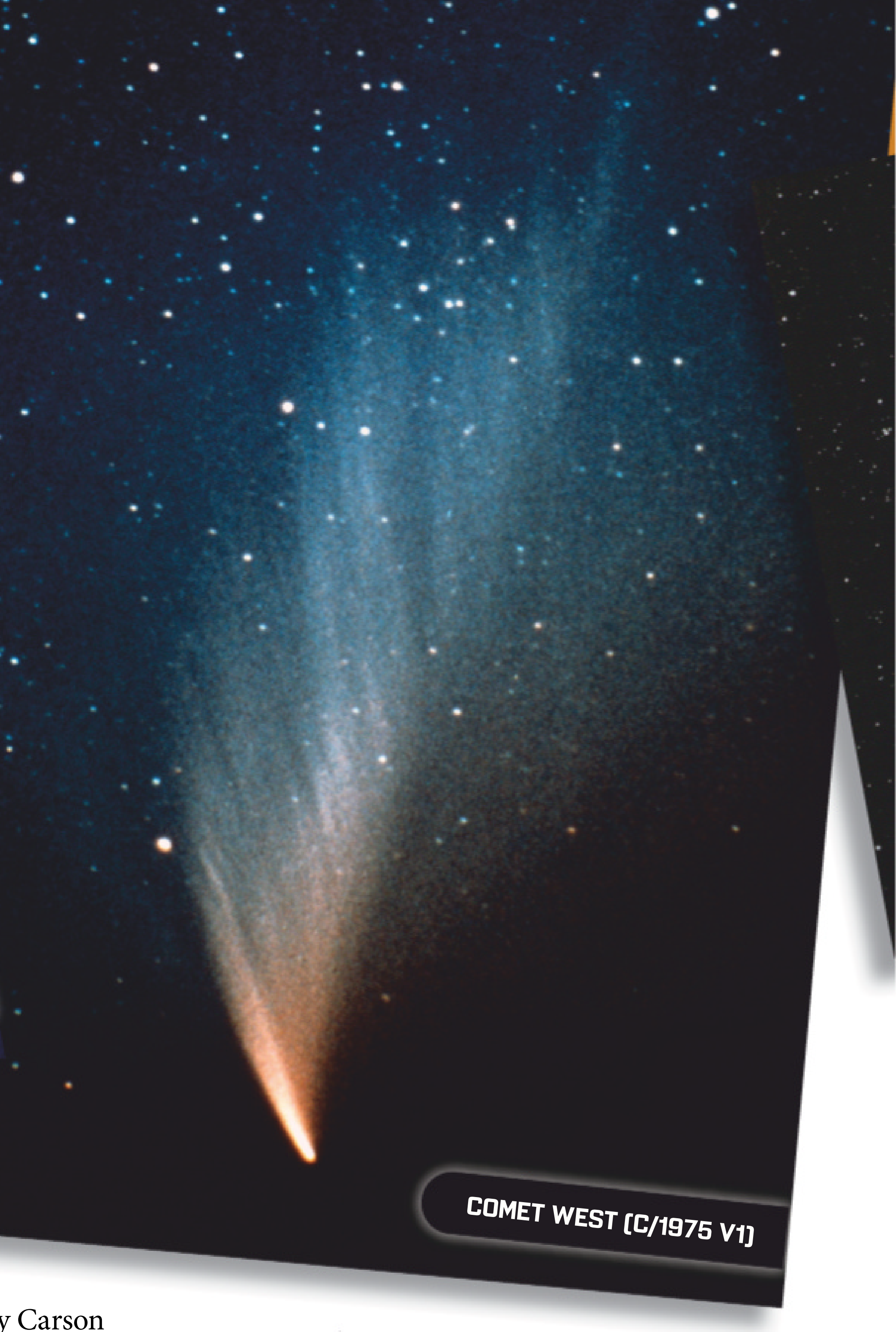
They didn't have long to wait. The comet reached perihelion (its closest point to the Sun) Oct. 21, when it was just 290,000 miles (467,000 kilometers) above our daytime star's surface. Ikeya-Seki was most visible the day of perihelion when, at midday in Japan, many observers detected it with their naked eyes in broad daylight. At its brightest, the comet reached an astounding magnitude –10, meaning that it shone about 10 percent as bright as the Full Moon, or 110 times brighter than Venus ever gets.

Images showed that, just before perihelion, the comet broke into three separate pieces. The two main ones will return around 2842 and 3021. This event mirrored the initial formation of the comet, which astronomers believe happened when the Great Comet of 1106 (X/1106 C1) broke up into thousands of smaller bodies.

Comet Bennett (C/1969 Y1)

Comet Bennett, the brightest comet seen after Ikeya-Seki, was a magnitude 8.5 object when South African amateur astronomer John Caister Bennett discovered it Dec. 28, 1969. It reached naked-eye visibility from dark locations in early February 1970. During the first week of March, it sported a tail some 10° long. It wasn't just the length of the tail, however, that thrilled observers. Bennett's tail contained a number of filaments, each of which resembled an individual comet's tail.





COMET KOHOUTEK (C/1973 E1) • Comet Kohoutek was the great comet that never delivered. Nonetheless, the University of Arizona's Lunar and Planetary Laboratory photographic team snagged this shot on Jan. 11, 1974, using a 35mm camera. NASA

COMET WEST (C/1975 V1) • Comet West reached peak brightness in March 1976, showing off its fan-shaped tail in this lovely photograph from that month. P. STÄTTMAYER/ESO

The comet reached perihelion March 20, 1970, when it approached to within 50 million miles (80.5 million km) of the Sun. Six days later, when Bennett was closest to Earth (64 million miles [103 million km]), it peaked at magnitude 0. When the comet was at its brightest, observers and scientists paid particular attention to the coma, which showed short features extending from the sunward side of the nucleus. Known as anti-tails, these components appear to point toward the Sun as Earth passes through the comet's orbital plane, but they're really just trails of dust left in the comet's wake.

Comet Kohoutek (C/1973 E1)

Let me be honest: The only reason Comet Kohoutek ranks as "great" is because the media hyped it as the "comet of the century." I fondly remember talk-show host Johnny Carson discussing Kohoutek with American astronomer Carl Sagan — but I don't remember the comet itself in a good light. We can think of it more as the great comet that never was.

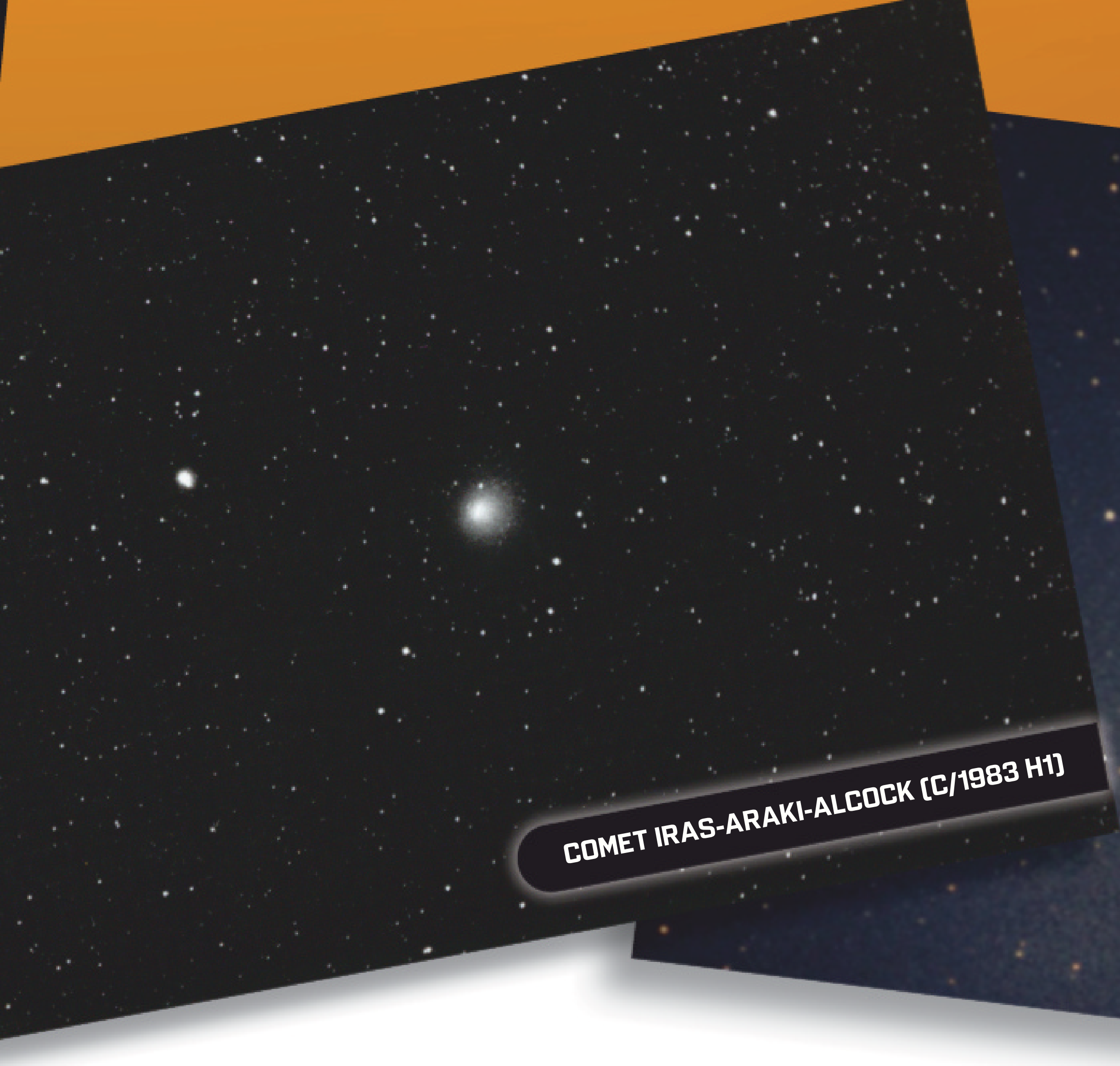
Astronomers believed Kohoutek would be a bright comet for two reasons. First, when it was discovered by Czech astronomer Luboš Kohoutek on March 18, 1973, it was nearly 442 million miles (711 million km) from the Sun. To be visible from such a distance meant that it must be a large body.

The second reason was that when researchers calculated its orbit, they realized this was Kohoutek's first visit to the inner solar system. Before then, it had resided in the Oort Cloud. That meant its outer layers were still pristine, having never been boiled away by repeated visits near the Sun.

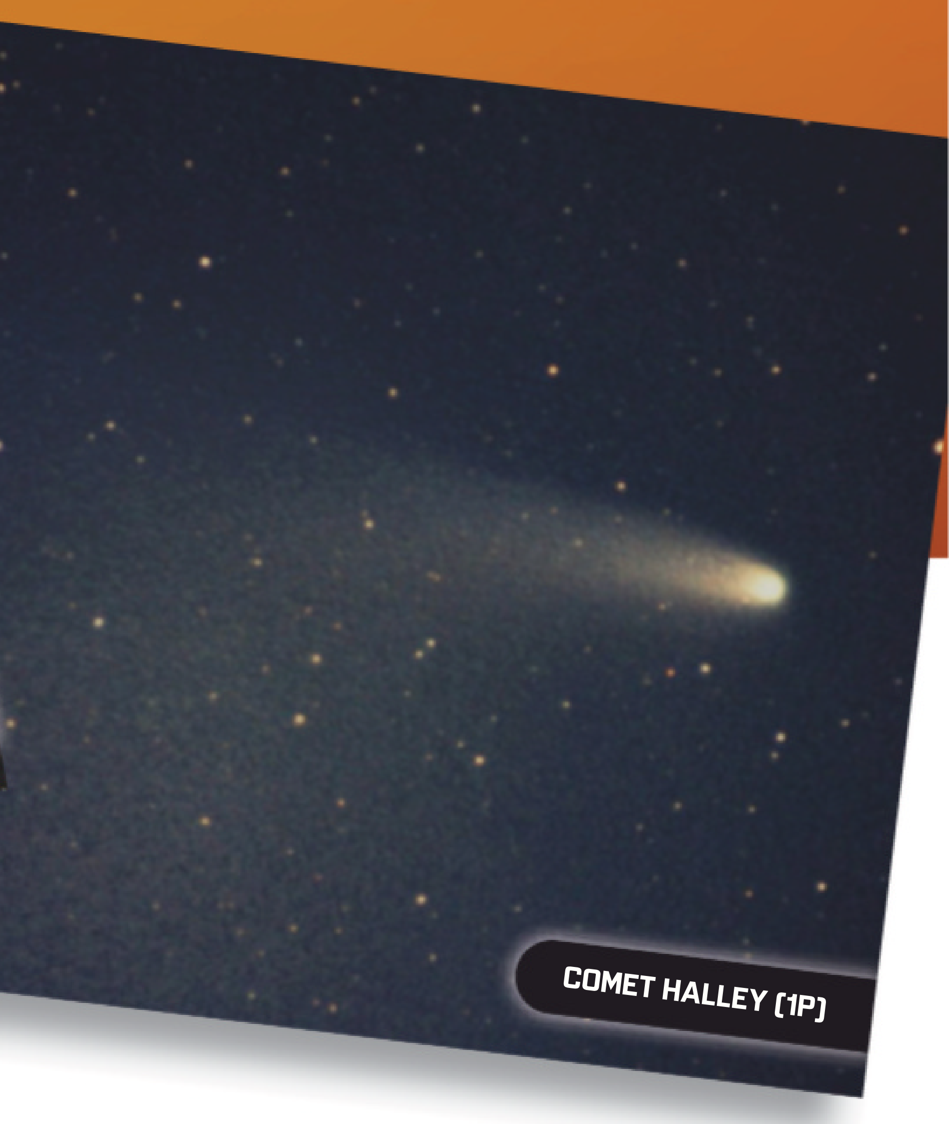
Unfortunately, Kohoutek brightened much more slowly than expected and proved a disappointment to the hundreds of thousands of people who went to view it. Still, it has one positive note: It was the first comet observed by astronauts in space. The crews of both NASA's Skylab 4 and the Soviet Union's Soyuz 13 missions reported seeing it.

Comet West (C/1975 V1)

Danish astronomer Richard M. West discovered the comet that would bear his name Nov. 5, 1975, in images taken at the European Southern Observatory in La Silla, Chile. As this was soon after the Comet Kohoutek debacle, most astronomers voiced low expectations for Comet West, saying it



COMET IRAS-ARAKI-ALCOCK (C/1983 H1) • This 15-minute exposure shows clearly how Comet IRAS-Araki-Alcock didn't look like a "normal" comet, thanks to its distinct lack of a tail. CHRIS SCHUR



COMET HALLEY (1P) • This image, taken on Kodachrome 200 slide film and pushed to 400 during development by the photographer, shows the most recent return of Halley's Comet in March 1986. MIKE BROUSSARD

probably wouldn't be an impressive sight when it emerged from behind the Sun.

What a nice surprise then, when for three days around its perihelion of Feb. 25, 1976, it reached magnitude –3 and became visible in broad daylight — the first comet since Ikeya-Seki to grow that bright. During the first week of March, its magnitude dropped to 0, but it sported a tail some 25° long.

At perihelion, West passed 18.3 million miles (29.4 million km) from the Sun. During its close encounter, tidal forces from our star broke the comet into four pieces.

Comet IRAS-Araki-Alcock (C/1983 H1)

If you were lucky enough to lay eyes on this object, you'll remember it didn't look like a traditional comet. In fact, Comet IRAS-Araki-Alcock didn't show a tail — at its brightest, it looked to the naked eye like an unresolved globular cluster. But with a diameter nearly as large as the Full Moon, it appeared a lot bigger than many globulars. It also was moving fast because it was so near to Earth. Indeed, at its closest point to Earth, it passed just 2.9 million miles (4.8 million km) from our planet, making it the closest comet since 1770. At this distance, IRAS-Araki-Alcock traveled across some 30° of sky per day. The comet glowed at 2nd magnitude at its brightest.

As is tradition with comets, this one is named for its discoverers. The first one, however, isn't a person. It's the Infrared Astronomical Satellite, or IRAS, which was active for 10 months in 1983. It imaged the comet April 25, 1983. The other two are people: Japanese amateur astronomer Genichi Araki and British astronomer George Alcock, both of whom independently discovered it May 3. Surprisingly, Alcock found the comet using binoculars from inside his home, while looking through a window.

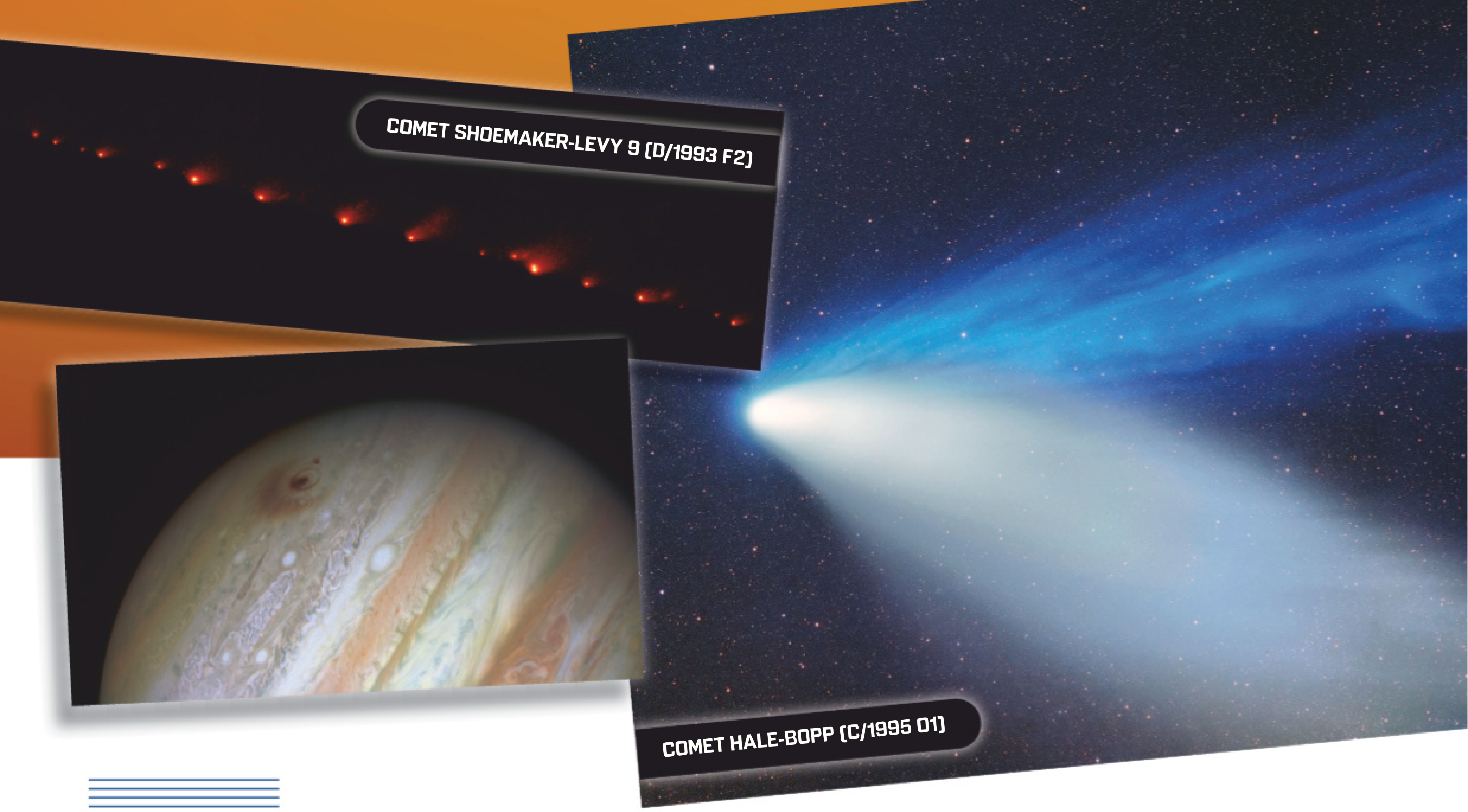
IRAS-Araki-Alcock is a long-period comet. It should return in 2953.

Comet Halley (1P)

I've often heard people say that non-astronomers recognize three celestial objects: the Moon, the rings of Saturn, and Halley's Comet. History's first identified periodic comet, 1P/Halley, returned to the night sky in 1982 for its most-observed appearance on record. And that's saying something, because it's been observed at least as far back as 240 B.C.

Unfortunately, during that recent appearance, celestial geometry wasn't on our side: Perihelion occurred Feb. 9, 1986, when Halley was on the opposite side of the Sun from Earth. Still, it peaked at magnitude 2.4 in early March, putting on a decent show for those in the Southern Hemisphere.

The comet is named for English astronomer Edmond Halley, but he didn't discover it. In 1705, he published a paper in which he wrote that the comets seen in 1531, 1607, and 1682 were all the same object. He further predicted that this comet would return to Earth's skies in 1758. And although Halley died in 1742 before he could see the outcome for himself, his prediction came true when observers


COMET SHOEMAKER-LEVY 9 (D/1993 F2)
COMET HALE-BOPP (C/1995 O1)

COMET SHOEMAKER-LEVY 9 (D/1993 F2) • In 1994, the Hubble Space Telescope observed the 21 pieces of Comet Shoemaker-Levy 9 (top) slamming into Jupiter, leaving dark blemishes in the gas giant's swirling atmosphere (bottom). NASA, ESA, AND H. WEAVER AND E. SMITH (STSCI); JUDY SCHMIDT (CC BY 2.0)

COMET HALE-BOPP (C/1995 O1) • The tails of Comet Hale-Bopp are a stunning sight in this image from March 27, 1997. GERALD RHEMANN

sighted the comet on Christmas night 1758.

Comet Halley's next perihelion will occur July 28, 2061. At that time, it is predicted to glow at magnitude –0.3, 12 times as bright as its peak in 1986.

Comet Shoemaker-Levy 9 (D/1993 F2)

A comet generally attains greatness either by being bright or by exhibiting strange features or movement. But there's one other way: It can hit a planet! Comet Shoemaker-Levy 9 (SL9) was discovered March 24, 1993, by American astronomer Carolyn Shoemaker, American geologist Eugene Shoemaker, and Canadian amateur astronomer David Levy.

By the time the trio found it, SL9 had been orbiting Jupiter for decades, after being captured by the planet's gravity. And it wasn't just trapped — tidal forces from the giant planet had broken the comet into more than 20 pieces.

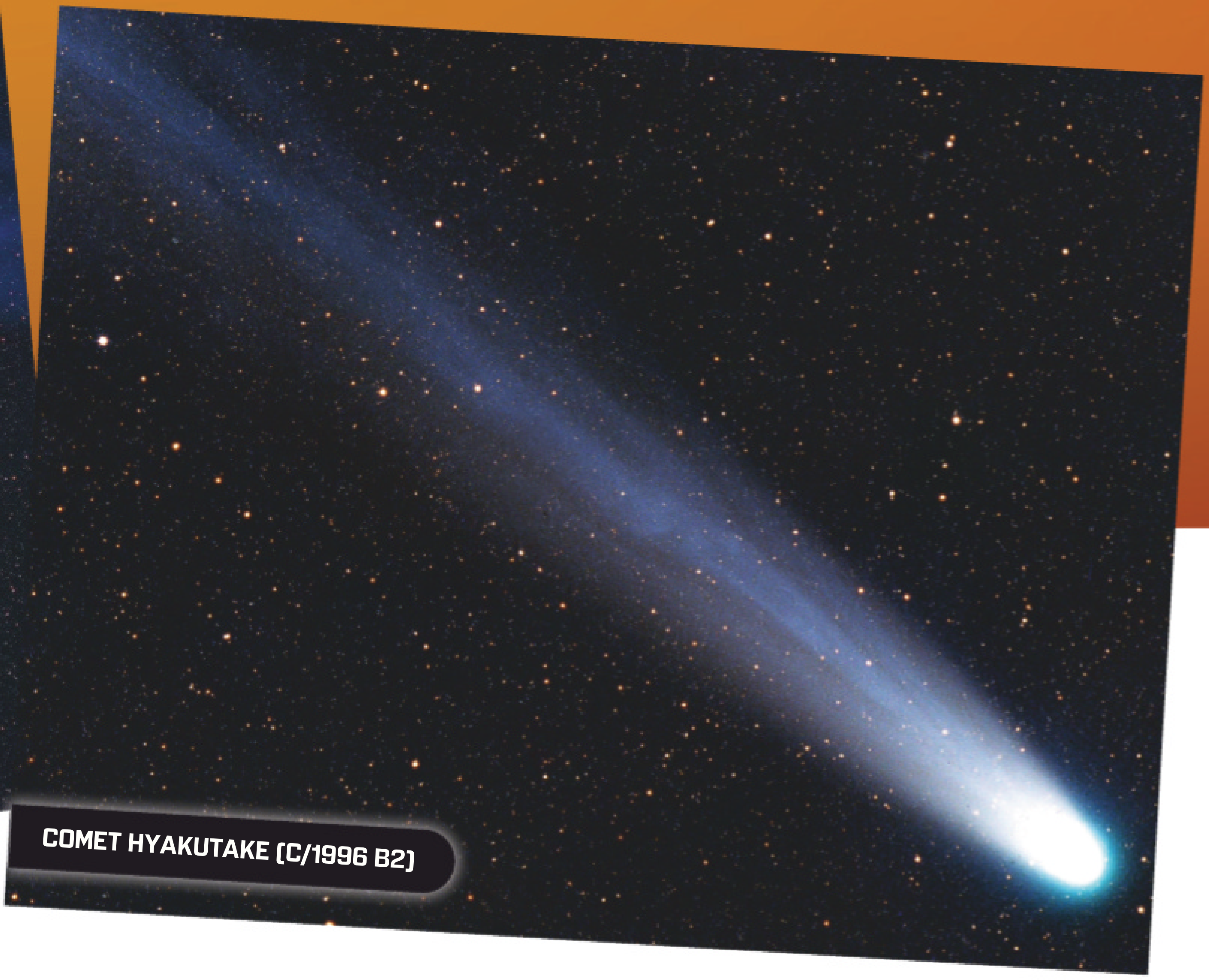
But the most exciting news came when astronomers calculated SL9's orbit. They found that its fragments would collide with Jupiter during a six-day stretch in July 1994. Each created a fireball — several visible from Earth — followed by the formation of a dark spot when debris from the fragment spread through the jovian atmosphere. The largest spot measured some 1,550 miles (2,500 km) across and was circled by two rings. The outermost ring was 7,500 miles (12,000 km) across, nearly as big as Earth.

The media was more than a little excited. But this time, it was a good thing. Indeed, the hoopla benefited astronomy clubs, whose members showed the public the new spots for several weeks. As the last spot faded, amateur astronomers thought, "We'll never have a comet that famous again in our lifetimes!" Uncharacteristically for astronomy, the wait for something better was less than two years away.

Comet Hale-Bopp (C/1995 O1)

American astronomer Alan Hale, observing from Cloudcroft, New Mexico, and American amateur astronomer Thomas Bopp, observing near Stanfield, Arizona, independently discovered Comet Hale-Bopp July 23, 1995. Both observers had been viewing the globular cluster M70 in Sagittarius and spotted the comet nearby. Orbital calculations showed that on the night they found it, Hale-Bopp lay some 7.2 astronomical units from the Sun, nearly twice the usual discovery distance for comets. (One astronomical unit, or AU, is the average distance between Earth and the Sun.)

Luckily, unlike Comet Kohoutek, Comet Hale-Bopp brightened according to predictions. It first became visible to the naked eye from the darkest sites May 17, 1996, and remained so for 18 months, surpassing the old record of nine months set by the Great Comet of 1811. On March 7, 1997, Hale-Bopp reached magnitude 0. Two weeks later, it peaked at magnitude –0.8, which is brighter than any star except Sirius (Alpha [α] Canis Majoris), with a tail that extended nearly 20°. It was last seen with the naked eye Dec. 9, 1997.



Stating that Hale-Bopp is a long-period comet seems a bit of an understatement. Its previous perihelion was in July 2215 B.C., when it may have been observed in Egypt. It will next reach perihelion in 4385 or later.

Comet Hyakutake (C/1996 B2)

Japanese amateur astronomer Yuji Hyakutake was surprised when he discovered this comet through 25x150 binoculars Jan. 30, 1996. It was in Libra, less than 4° from where he had found a different dirty snowball on Christmas night the previous month. Comet Hyakutake continued to surprise observers, many of whom (myself included) say that it's the greatest comet they've ever seen.

The comet reached naked-eye visibility Feb. 26 and began a fairly quick rise in brightness through March. It peaked at magnitude 0 late that month. Comet Hyakutake sported a spectacular tail, which observers at dark sites could see stretch for 100°.

But the tail's length was only half the story. On March 25, the night of Hyakutake's closest approach to Earth, observers reported that colors were easily visible throughout its length. Streamers in the tail exhibited various shades of blue, purple, and green. The coma also put on a show. Around this time, it had a diameter of 1.5°, three times the width of the Full Moon.

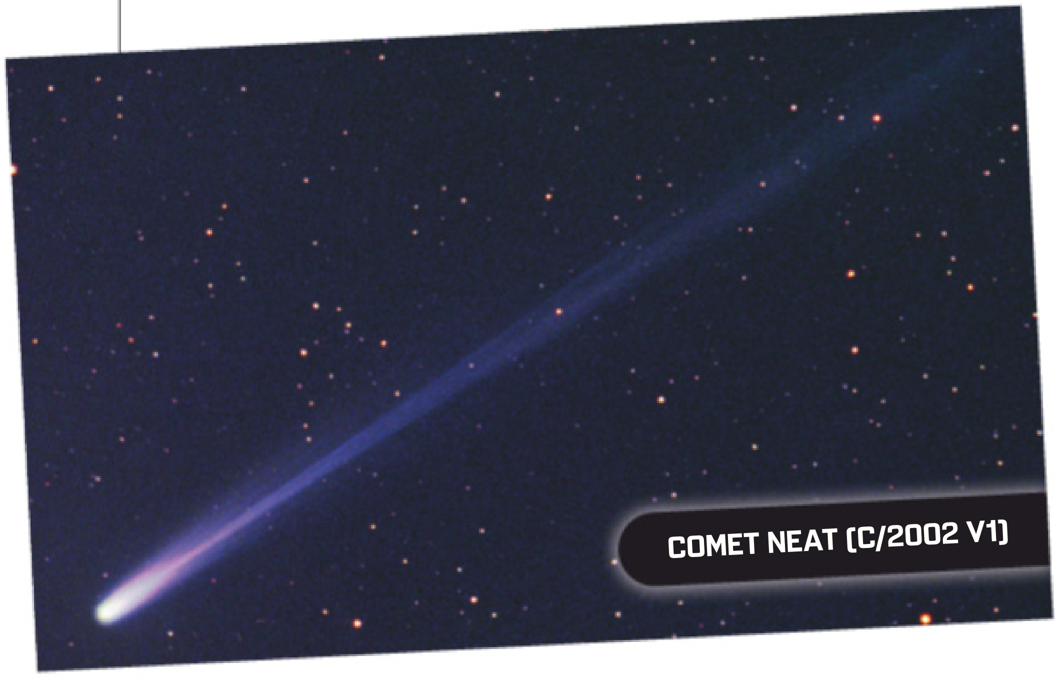
Apart from its closest approach, probably the most thrilling sight was when observers in Europe and the U.S. saw it alongside a totally eclipsed Moon April 3/4. The final naked-eye report came May 29. Unfortunately, it will be another 98,000 years or so before Hyakutake returns to the inner solar system.

Comet NEAT (C/2002 V1)

This comet was discovered Nov. 6, 2002, on an exposure taken by the 1.2-meter Schmidt telescope located at the Near-Earth Asteroid Tracking observatory in Hawaii. NEAT was a program run by NASA and the Jet Propulsion Laboratory from 1995 until 2007. The comet reached perihelion Feb. 18, 2003. At that point, it was only 9.2 million miles (14.8 million km) from the Sun.

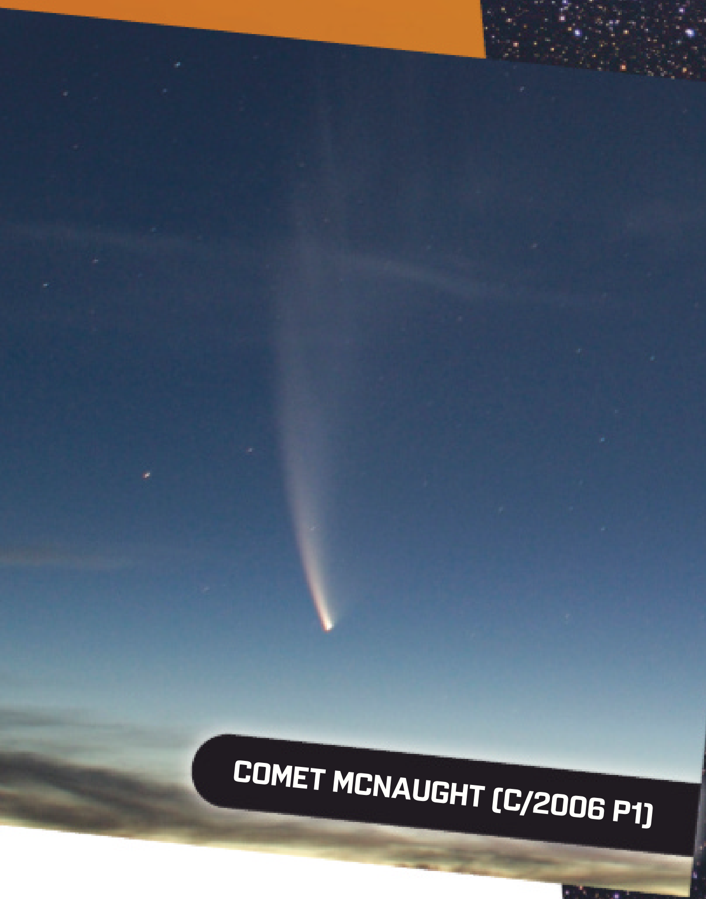
Although some astronomers predicted that a comet as small as NEAT wouldn't survive its close encounter with the Sun, it did. Scientists estimate it will return in approximately 37,000 years. At its brightest, the comet shone at a worthy magnitude –0.5.

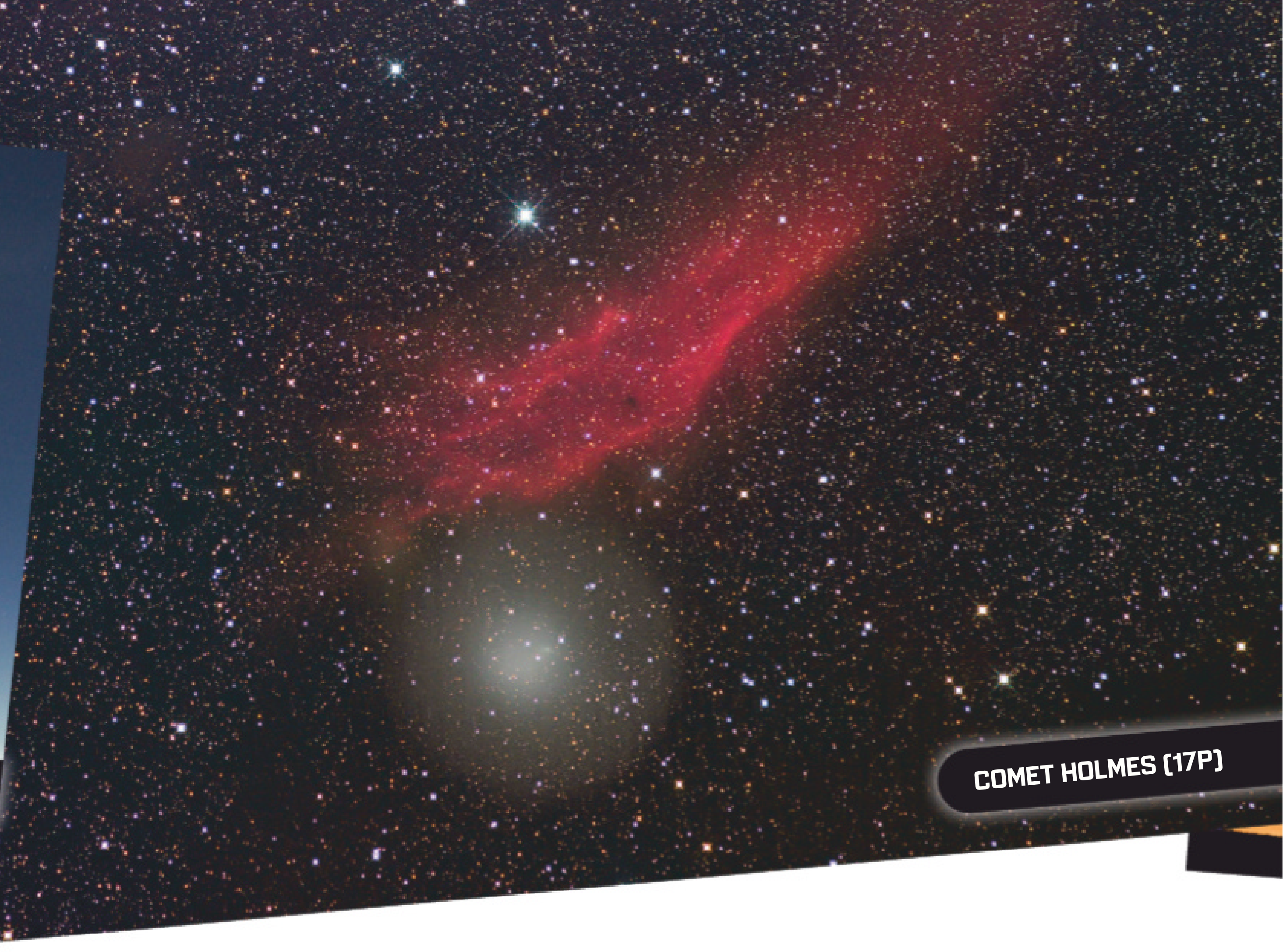
One interesting coincidence occurred



COMET HYAKUTAKE (C/1996 B2) • Comet Hyakutake shows off colorful streamers in its lengthy tail as it streaks across the sky in 1996. GERALD RHEMANN

COMET NEAT (C/2002 V1) • This Feb. 2, 2003, image shows Comet NEAT prior to its perihelion, during which it passed close to the Sun. GERALD RHEMANN





COMET MCNAUGHT (C/2006 P1) • It's easy to see in this photo, taken Jan. 22, 2007, from Maldonado, Uruguay, why Comet McNaught dazzled Southern Hemisphere observers. CIRO MONDUERI (CC BY 2.0)

COMET HOLMES (17P) • This photo shows off Holmes' expansive coma as the comet swept past the California Nebula (NGC 1499) in Perseus in February 2008. GERALD RHEMANN

when a coronal mass ejection hit the comet Feb. 17, a day before perihelion. NEAT's nucleus was unaffected, though astronomers saw signs of an interaction between the solar material and the comet's tail.

Comet McNaught (C/2006 P1)

Scottish-Australian astronomer Robert H. McNaught discovered his 31st comet (out of 82 total) in the constellation Ophiuchus on Aug. 7, 2006. But this Comet McNaught would prove more wonderful than all his other discoveries put together. Indeed, it became the second-brightest comet since 1935, topped only by Ikeya-Seki in 1965.

Its journey into the inner solar system took it within 15.9 million miles (25.6 million km) of the Sun on Jan. 12, 2007, the date of its perihelion. It peaked in brightness the following days at magnitude –5.5, bright enough to see during daylight hours. The comet was a stunner in the Southern Hemisphere, sporting luminous bands in a tail that stretched some 35°.

The nucleus of Comet McNaught originated in the Oort Cloud, a collection of trillions of icy bodies that lie in a sphere between 2,000 and 100,000 AU from the Sun. As such, it was a first-time visitor that took uncounted millions of years to reach us. Calculating its return is a bit sketchy, but astronomers' best guess is that it will reappear in approximately 92,000 years.

Comet Holmes (17P)

Comet Holmes, the 17th recognized periodic comet, was discovered Nov. 6, 1892, by British amateur astronomer Edwin A. Holmes. Although Holmes has a period of 6.9 years, it's only been observed a few times since its discovery (generally because it is too faint). One of them, however, stands out.

Holmes put on a terrific show in the fall of 2007 with a brilliant outburst months after its May 4 perihelion. In just 42 hours during Oct. 23 and 24, it brightened more than 478,000 times: from magnitude 17 to magnitude 2.8. It peaked at magnitude 2.4 by the end of the month. During that time, Holmes' coma expanded to an apparent diameter of nearly 1°.

Who knows if the comet will put on another repeat performance in the future. Be sure to follow its next perihelion, which will occur Jan. 31, 2028.

Comet Lovejoy (C/2011 W3)

Australian amateur astronomer Terry Lovejoy's third comet discovery (he currently has six) took place Nov. 27, 2011. Based on its orbit, astronomers found the celestial visitor was a sungrazer that would pass within 516,000 miles (830,000 km) of the Sun at perihelion Dec. 16. When they studied the orbit, they concluded the comet was one of a special group known as Kreutz sungrazers. Researchers believe each of these objects originated when a single large comet broke up, probably several thousand years ago. At least half a dozen comets from this group have attained "great" status, including the Great Comet of 1882, which, at an estimated magnitude –17, shone more than 50 times brighter than the Full Moon. Ikeya-Seki was another famous Kreutz sungrazer.

Many experts expected the small comet to break up during its close passage, but Comet

COMET LOVEJOY (C/2011 W3)

COMET LOVEJOY (C/2011 W3) • Comet Lovejoy's tail stretches through the sky above Araraquara, Brazil, on Christmas Eve 2011.
RENATO PIMENTEL (CC BY-ND 2.0)

COMET PANSTARRS (C/2011 L4)

COMET PANSTARRS (C/2011 L4) • Comet PanSTARRS never rose out of the bright twilight, making it a better target for binoculars and photographers than naked-eye observers.
CHRIS SCHUR

COMET NEOWISE (C/2020 F3)

COMET NEOWISE (C/2020 F3) • Comet NEOWISE stunned in photographs, showing off great detail in its ion and dust tails.
CHRIS SCHUR

Lovejoy survived its plunge into the Sun's corona. And although it was difficult to observe because it was so close to the Sun, amateur astronomers estimated it peaked at magnitude –1 after perihelion. It will next return around 2633.

Comet PanSTARRS (C/2011 L4)

On June 6, 2011, C/2011 L4 became one of many comets discovered by the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) 1 telescope in Hawaii. At the time, it lay some 730 million miles (1.2 billion km) from the Sun, so hopes were high that it would become bright.

PanSTARRS was first sighted by naked-eye observers Feb. 7, 2013. It passed closest to Earth on March 5 and reached perihelion five days later. Its brightness was difficult to estimate because the comet never rose high above the horizon. It peaked around 1st magnitude, but most observers recall that it was a stunning binocular object.

Comet PanSTARRS followed a hyperbolic orbit, which would normally mean it will never return. Gravitational interactions with the Sun and planets, however, altered its orbit slightly, so astronomers now think it will return — in 105,000 years!

Comet NEOWISE (C/2020 F3)

The final comet on our list was discovered by a team of researchers March 27, 2020, using the Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE). When astronomers calculated its orbit, they found it would reach perihelion July 3, passing 27 million miles (44 million km) from the Sun.

Before perihelion, NEOWISE required a telescope or large binoculars. Afterward, however, it brightened significantly for a few days. At its best, the comet reached magnitude 1.5. Those using binoculars and telescopes could see the comet's tails, but these features really showed detail in photographs. At their longest, both the ion tail and the dust tail were more than 50° long.

NEOWISE is a long-period comet. Before perihelion, its orbital period was about 4,400 years. But after its interactions with objects in the inner solar system, the period lengthened to nearly 6,800 years. Did it reach great comet status? Observers who say yes cite its magnitude, even though it was only bright for a couple of days.

Keep hope alive

Bright comets can help us spread our love of astronomy to the general public. Surveys and observers now discover roughly 200 comets each year. Let's hope one of them in the near future rises to greatness.

Michael E. Bakich *is a contributing editor to* Astronomy *whose many orbits around the Sun mean that he recalls each of the comets in this list.*

Catching COMETS on CAMERA

These fleeting beacons from the outer solar system make for fantastic shots.

BY DAMIAN A. PEACH

THE WORLD OF COMETS

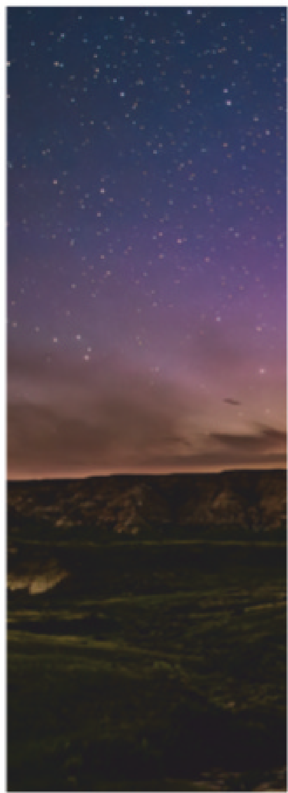
OVER THE LAST FEW YEARS, we have been fortunate to be treated to several dramatic comets gracing our skies. Comets C/2020 F3 (NEOWISE) and C/2021 A1 (Leonard) were both wonderful objects to observe and image, with NEOWISE being one of the most impressive naked-eye comets of the 21st century.

The timing of recent comets couldn't be better from an imaging standpoint, either. Since their introduction decades ago, digital cameras have grown steadily in popularity and prevalence, so that nearly every amateur astronomer now has one — and the accompanying improvements in light sensitivity has made image processing easier than ever before. Plus, thanks to smartphones, pretty much everyone is equipped with a camera that is good enough to catch shots of these brief visitors from the outskirts of our solar system.

Dirty snowballs

Before you plan your composition and set up your equipment, you might be wondering what features you should be on the lookout for.

Comets are small bodies of ice, rock, dust, and frozen gases which



CLOCKWISE FROM TOP: Comet Leonard, captured here at its peak, has a multitude of fine tail streamers emanating from its nucleus. Brighter comets can be among the most spectacular objects in the sky to observe and photograph. DAMIAN PEACH

Near its peak brightness in July 2020, Comet NEOWISE sports a yellowish fanned dust tail and narrow blue ion tail typical of brighter comets. DAMIAN PEACH

Comet NEOWISE captured the world's attention in 2020. This image was taken over the badlands and formations of Dinosaur Provincial Park, Alberta, on July 14/15. ALAN DYER

CAMERA: DIMITRY ROMANCHUCK/DREAMSTIME

astronomers think originate from the distant reaches of our solar system. As these bodies slowly draw closer to the Sun, solar heating causes volatile materials within to vaporize. This blows dust away from the comet's nucleus, forming a large, tenuous atmosphere around it called a coma.

Pressure from solar radiation and the solar wind then shapes this coma into a tail of dusty material pointing away from the Sun. This dust tail is sometimes visible to us on Earth because it reflects sunlight. And occasionally, a second tail can form from the gases that are released by the comet. This is often called the gas tail or ion tail, which glows not due to solar illumination but ionization.

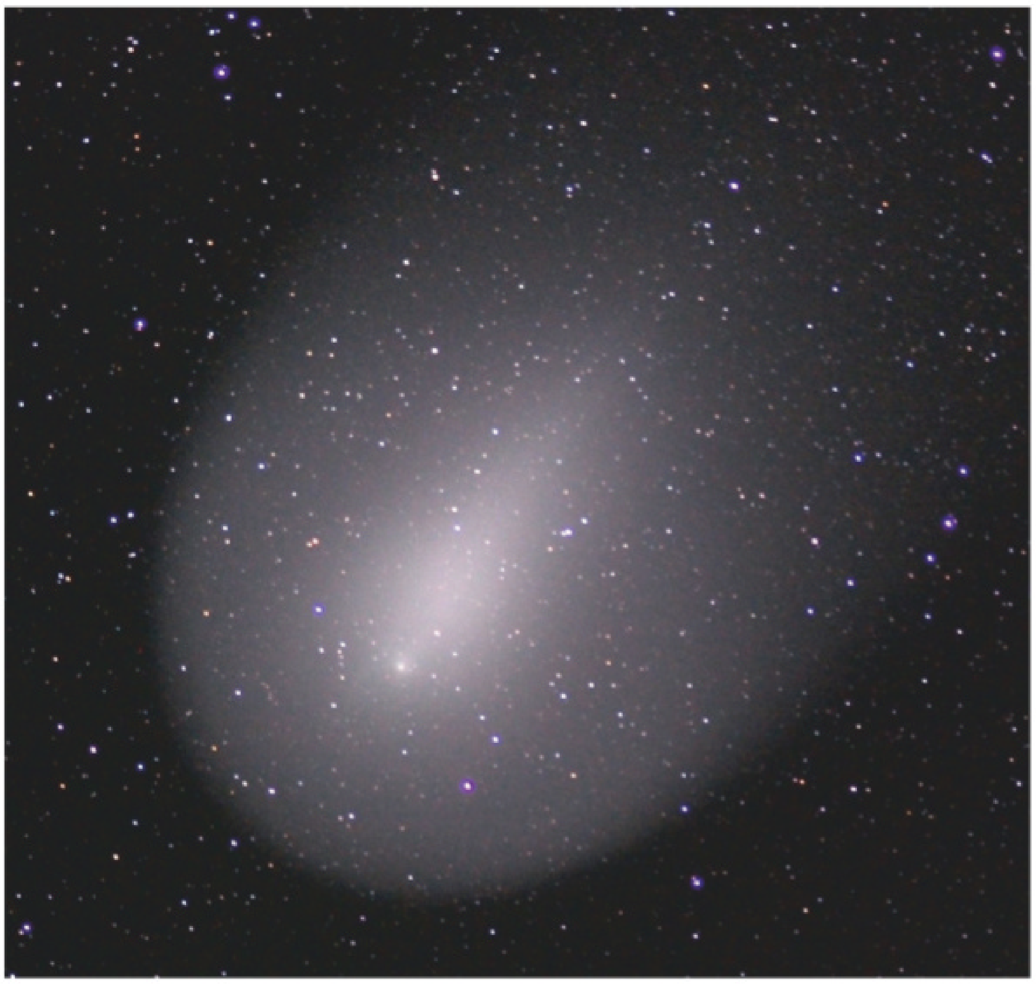
Material from the dust tail escapes the comet's gravitational grasp, spreading out behind the comet along its orbital path, often taking on a curved shape. Meanwhile, the ion tail, which is more strongly affected by the solar wind, always points directly away from the Sun. An ion tail typically presents a notable bluish color, in stark contrast to the hazy white hue of a dust tail.

If it's a bright comet, there might even be a third tail called the anti-tail. This tail can be seen emanating from the nucleus and seemingly pointing toward the Sun. However, this is an optical illusion that can appear as Earth crosses the plane of the comet's orbit when the body is close to the Sun. When viewed from edge-on, the thin sheet of cometary dust lagging behind the comet looks like a sunward pointing spike.

Comets typically come in two main flavors: short- and long-period. Short-period comets circle the Sun in less than approximately 200 years, while long-period ones can take thousands to millions of years to complete a single orbit.

There also exists a third type of comet, known as a sungrazer. This special class is responsible for many of the most spectacular comets seen throughout history. Sungrazers are characterized by very small perihelion distances — meaning they pass extremely close to the Sun — which can make them appear spectacularly bright for a brief period.

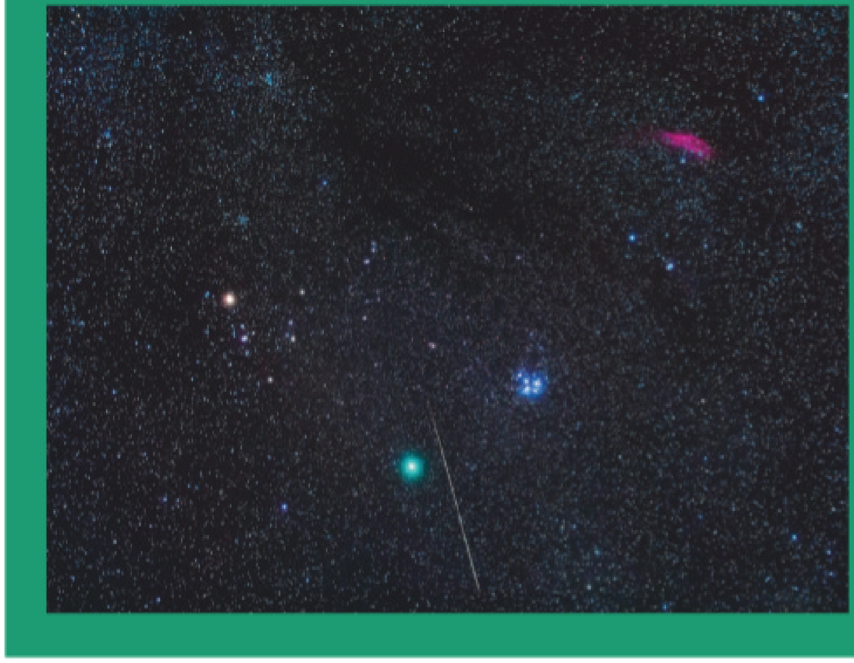
Many great comets throughout history were sungrazers, including C/1965 S1 (Ikeya-Seki), C/1975 V1 (West), and C/2006 P1 (McNaught). More recently, in 2013, Comet C/2012 S1 (ISON) came within about 730,000 miles (1.2 million km) of the Sun. Before its approach, giddy observers dubbed it the "comet of the century." Unfortunately, ISON disintegrated shortly after its perihelion pass and never lived up to its dazzling expectations. But that's the frustrating thing about comets that you simply have to live with: You never quite know what you're going to see!



RIGHT: Comet 17P/Holmes, near its maximum brightness back in late 2007, was captured using a DSLR camera attached to a small 3.2-inch telescope. Several 15-second exposures were combined to reduce noise. Even basic equipment can capture impressive images of brighter comets. DAMIAN PEACH

BELOW: Views of Aldebaran and Hyades (left), the California Nebula (top right), and the Pleiades (center right) were graced by Comet 46P/Wirtanen and a Geminid meteor Dec. 14/15, 2018. ALAN DYER

COMET CONJUNCTIONS



BECAUSE COMETS RACE THROUGH the sky, they often pass close to other celestial objects, such as nebulae and galaxies. These brief conjunctions between comet and deep-sky object can present you with the chance to capture a unique and spectacular image. But your window of opportunity during any cometary conjunction is typically only a day or two, at most. That's why it's worth checking out your comet's projected course across the sky ahead of time, noting any bright deep-sky objects it will visit. Fortunately, most planetarium programs can display this information for you. *—D.A.P.*

DSLR photography

Unlike many forms of astrophotography, which can be quite costly and complex, shooting bright comets is a surprisingly straightforward yet greatly rewarding pursuit. Keeping a few simple points in mind, anyone with a quality camera can easily capture spectacular images of these stunning celestial bodies.

For bright comets, which we will define here as those visible to the naked eye, a digital SLR equipped with a standard 18–55mm lens and mounted on a sturdy tripod will suffice. First, set the camera to operate in "M" (manual) mode, giving you full control over the camera settings. Carefully focus the camera on a bright star, the Moon (if available), or even the comet itself, if it's bright enough for the autofocus to latch onto it. Most DSLRs today are equipped with a "live view" mode that allows you to focus the lens using a magnified real-time view through the camera's LCD display. This feature is extremely useful for easy, accurate focusing.

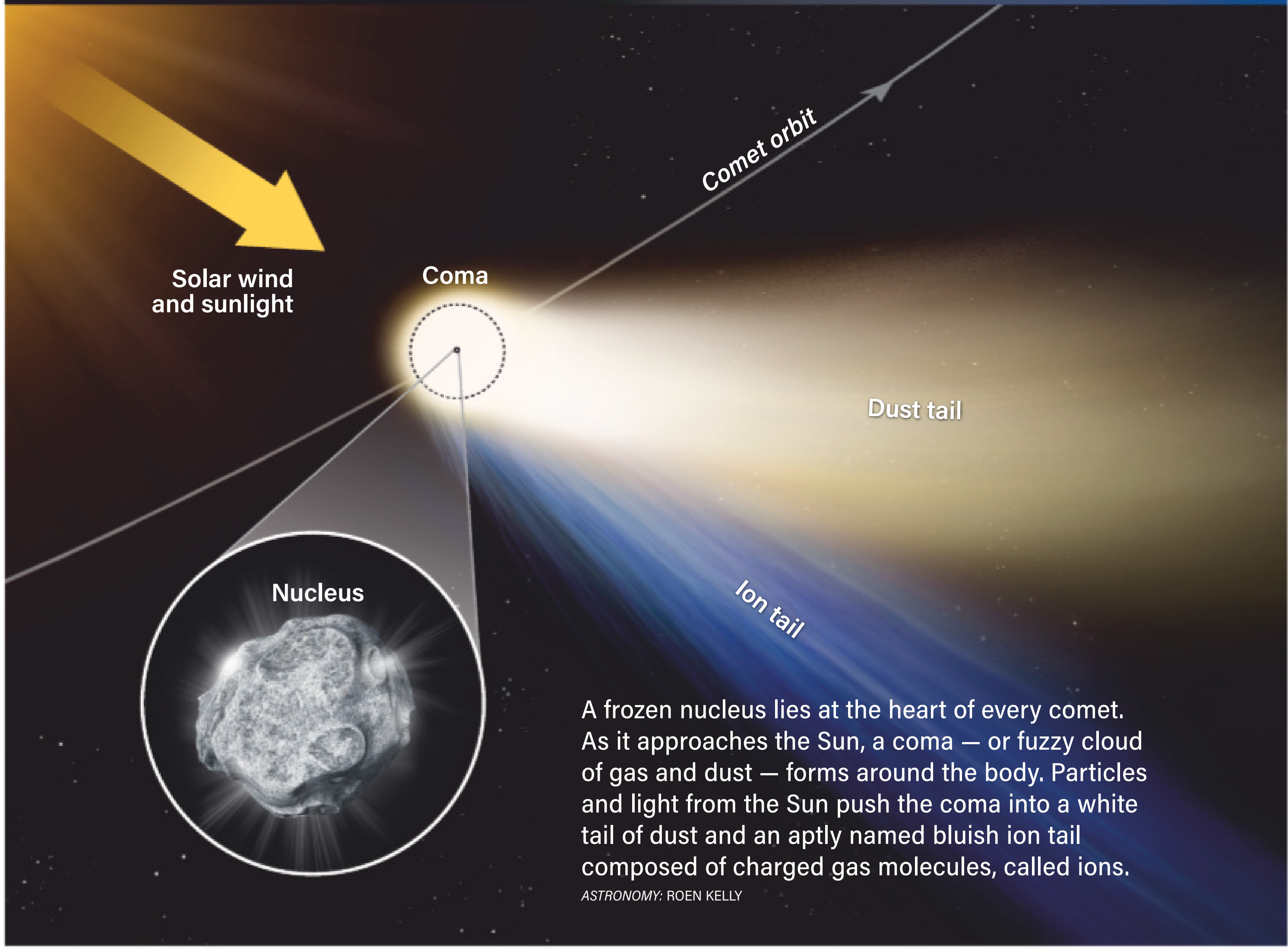
Next, you'll want to set the lens aperture to its widest value, or lowest f-number. You'll also want to set the ISO sensitivity to around 400 to 800 for bright comets. For fainter comets, you might get better results with a higher ISO, somewhere in the 1600 to 3200 range. Keep in mind, however, higher ISOs lead to noisier images.

A sturdy tripod is a must for any form of astrophotography. You also might want a remote release so that you can trigger the camera shutter without having to touch it and risk blurring the image. However, DSLRs have various time-delay modes; so you can physically press the shutter-release button, and then the camera will wait a few seconds before opening the shutter for a set amount of time. I have used this mode on many occasions with great success.

Once you begin taking images of your comet, experiment with different exposure times. Your ideal exposure time will depend on your camera, how bright the comet is, and how bright your local sky is. In general, however, you will always want to keep your single exposures to around 15 seconds or less to avoid star trails. The higher the focal length of your lens, the shorter exposure time you'll need to use to avoid trailing. You can also combat trailing by attaching your camera to a small driven mount, but that might not be an option for everyone. And, of course, maybe you want star trails in your shot!

Although it takes a bit more work, the best way to truly capture the beauty of comets is to take a series of shots and then stack them together to enhance details and reduce background noise, especially if using higher

ANATOMY OF A COMET



A frozen nucleus lies at the heart of every comet. As it approaches the Sun, a coma — or fuzzy cloud of gas and dust — forms around the body. Particles and light from the Sun push the coma into a white tail of dust and an aptly named bluish ion tail composed of charged gas molecules, called ions. *ASTRONOMY:* ROEN KELLY

LEFT: Comet C/2015 V2 (Johnson) was an impressive object for small- to medium-sized telescopes. It's fairly common to have a few comets like this pass through our skies in any given year; they often make great targets for imaging. DAMIAN PEACH

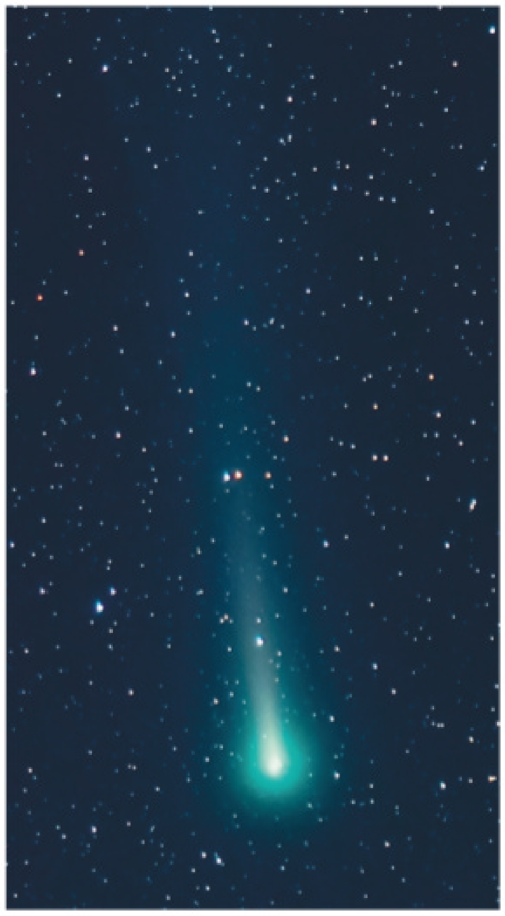
CONSUMER CAMERAS

THE CONSUMER-CAMERA INDUSTRY is quickly transitioning from DSLRs to mirrorless cameras, which are lighter and have some advantages, especially for photographers on the go. There are mirrorless models that are well-suited or even designed for astrophotography — but they tend to be more expensive than their older DSLR counterparts. While you may not be able to find a new DSLR for sale much longer, rest assured that DSLRs and their lenses will continue to be the trusted choice of many astrophotographers, including the budget-minded, for years to come. —*Mark Zastrow*

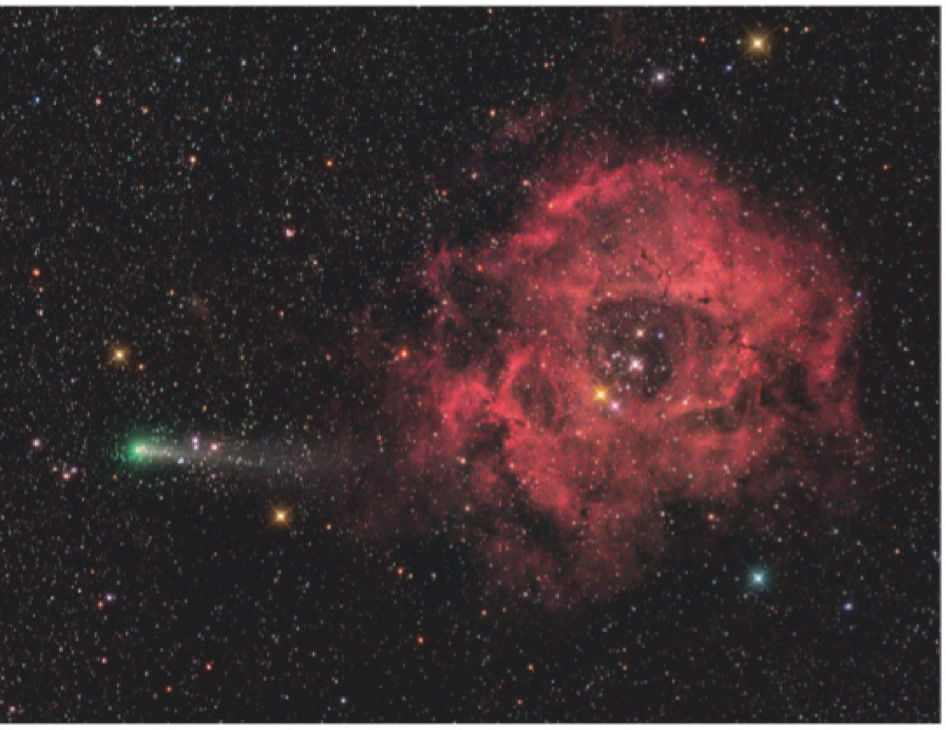
ISO settings. There are many programs available that allow you to easily stack images. The planetary image-processing program RegiStax will do a good job stacking images from DSLR cameras, and it's also very easy to use. DeepSkyStacker also works well, and both programs are free to download.

Imaging through a scope

A telescope opens up a whole range of fainter comets for imaging, not just those rare and spectacular naked-eye sights. At any one time, there can be hundreds of dim comets within reach of an amateur scope mounted with a high-quality camera. Although most are likely too faint to be worth capturing, often, there are several gracing the sky at once, and they make for excellent targets through small scopes.



RIGHT: Comet Leonard appears to have a tail stretching some 3.5° in this image captured Dec. 10, 2021. ALAN DYER



BELOW: Comet C/2013 V5 (Oukaimeden) was only close to the famous Rosette Nebula in Monoceros for just over a day, so the window in which to capture this view was brief. Planning ahead — combined with some lucky weather — ensured this breathtaking sight! DAMIAN PEACH

Pretty much any telescope can be used to shoot comets. But observers tend to favor fast refractors, Newtonians, and Ritchey-Chrétiens for their wide, flat fields of view and fast f-ratios.

A telescope opens up a whole range of fainter comets for imaging, not just those rare and spectacular naked-eye sights.

Although DSLRs will still produce good results, many observers opt to use dedicated astronomical CCD cameras, such as those manufactured by companies like SBIG and FLI. These cameras are certainly not cheap, but they do offer the highest image quality. Using dedicated CCD cameras requires the usual methods associated with deep-sky astrophotography, such as using dark frames and flat fields to fully calibrate the images before processing.

Planning your imaging session is especially important when using your telescope. Many comets reach their peak brightness when they are located low in the twilight sky, so time is often limited when it comes to capturing good data.

Quality planetarium software is essential to planning observations, especially for comets. Many software packages are available, such as TheSky, Starry Night, and Cartes du Ciel. Planetarium programs like these allow you to carefully plan out your observing session, helping you maximize your data and, therefore, the quality of your final image.

You'll also need to update the program's comet orbital elements using the Minor Planet Center's ephemerides. (See the "Further Reading" sidebar on the next page.) These are databases that provide the calculated positions of celestial objects; this will ensure the positions of known comets are displayed accurately, as well as add any new comets as they are discovered. These programs also allow you to input your camera and telescope field of view to allow you to better plan out your composition by carefully positioning the comet on the camera sensor for optimal framing.

When imaging most comets through a telescope, you'll immediately notice that your target moves with respect to the background star field. Some comets move across the sky much faster than others, but usually, any single exposure longer than four to five minutes will result in trailing of the comet itself in your image. The easy solution to this is to take several short exposures, such as five 60-second shots, and then stack them together. This will result in a clean and sharp comet, but it will also leave you with a trailed star field. Nonetheless, this method is the one employed by most telescopic comet observers.

If you want to avoid trails altogether, you can use a more complex image processing routine that combines two different master image stacks: one short-exposure stack showcasing trail-less stars and another long-exposure stack that makes the comet really pop.

Remote imaging

Another fantastic way to capture stunning photographs of comets is by using remotely operated

The summer Milky Way sets behind the Chilescope Observatory. The center of our galaxy is an incredible sight under the dark and transparent sky of the Atacama Desert.

DAMIAN PEACH

telescopes. These telescopes are located under extremely dark skies and are a great option for those stuck under cloudy or light-polluted skies. For a modest fee, you can log onto a telescope online and control it in real time to target the object of your choice. During your slated observation window, you are provided with live views of the sky and weather, you can view images from the telescope as they are captured, and you can download your data in the usual FITS format for processing.

The real benefit here, however, is that this method gives you access to telescopes located at top-tier dark-sky locations, all without leaving the comfort of your own home. Many telescopes, both amateur and professional, are successfully operated in this manner today, and I've carried out numerous observations this way.

Several remote observatories ranging in both capability and location are now available to amateurs. Providers such as Chilescope, iTelescope, TelescopeLive, and Slooh all offer a multitude of telescope systems suitable for remotely imaging comets. Another bonus of this approach is that most comets are bright enough that they don't require lengthy exposures. Since many remote services charge based on exposure time, from a financial perspective, remote comet imaging is quite affordable for most — unlike observing a deep-sky object for multiple hours.

No matter how you choose to capture your next — or first — image of a comet racing across the night sky, don't forget you're observing an ancient relic left over from the very formation of our solar system. Throughout history, these beacons have been viewed as both joyous heralds of the gods and dread-inspiring harbingers of doom. But now we know they do not, in fact, signal our fate. That's in our own hands.

So, next time a comet graces the skies, grab your gear, get outside, and start shooting!

Damian A. Peach *is an amateur astronomer, veteran astrophotographer, and a long-time contributor to* Astronomy.

FURTHER READING

BOOKS: *Hunting and Imaging Comets* (Springer, 2010), by Martin Mobberley

FOR THE LATEST COMET INFORMATION: http://www.aerith.net

MINOR PLANET CENTER OBSERVABLE COMETS:
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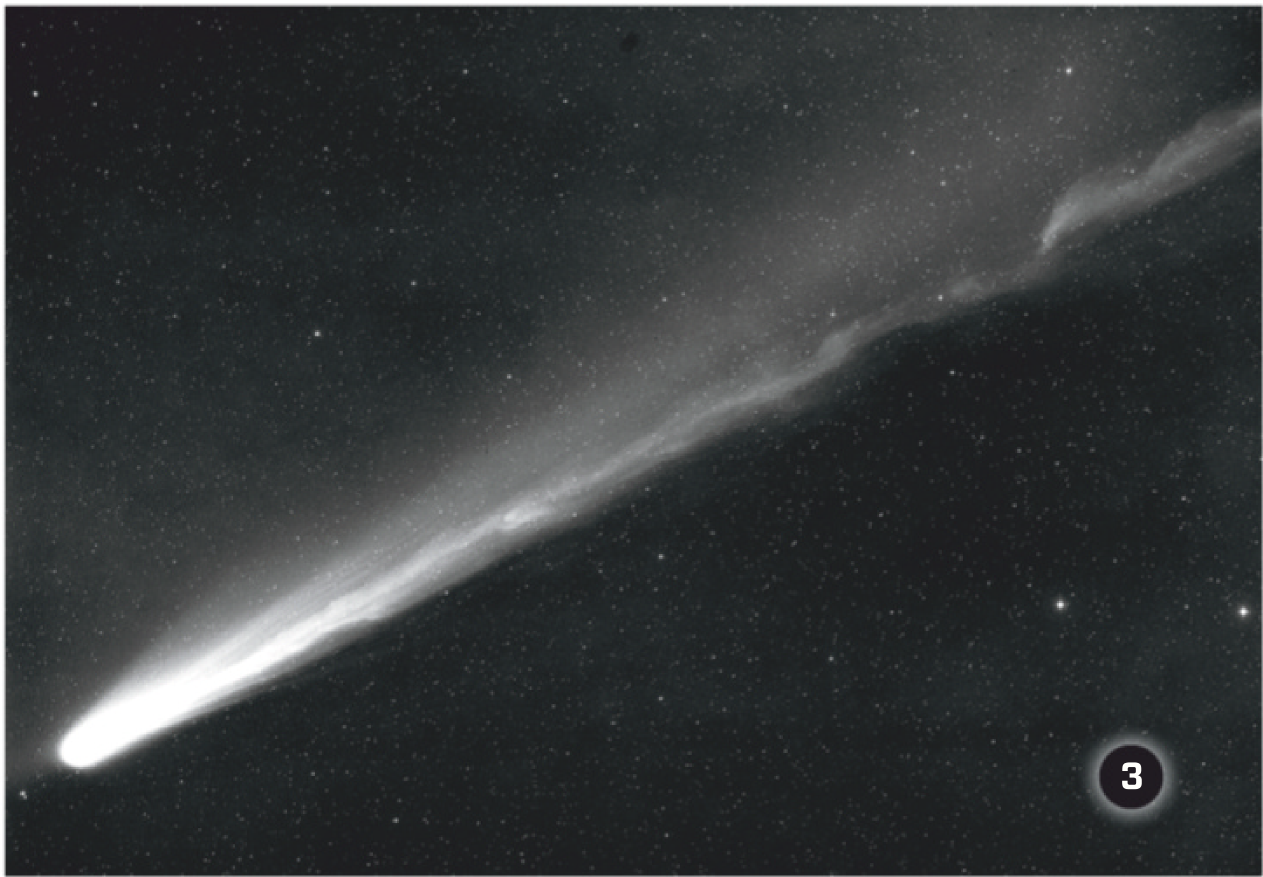

3

A gallery of GREAT COMETS

THE WORLD OF COMETS

Specters of comets have filled the night sky across the eons. Here are some of the recent best. BY MARK ZASTROW

COMETS PROVIDE PHOTOGRAPHERS with endless possibilities. They are dynamic close-up subjects: capable of shifting their form from night to night, sprouting nebulous comae, and even undergoing outbursts. Comets are also itinerant photobombers, regularly crossing paths with familiar deep-sky objects as they glide elliptically against the celestial sphere. And when great comets graze the Sun and unleash their tails across the entire sky, they make for spectacular wide-field vistas.

Where once these landscapes were captured only in sketches and paintings, the steady march of technology has enabled astroimagers to record them in increasingly stunning photographs. The images here capture some of the great (and nearly great) comets of the past six decades.

1 Ikeya-Seki (C/1965 S1)

Discovered in September 1965, this sungrazer lived up to all expectations. Over the next month, it blossomed into one of the brightest comets of the millennium — an indisputably great comet. This four-minute exposure was taken at dawn from Kitt Peak National Observatory Oct. 29, 1965, eight days after perihelion. ROGER LYNDS/NOIRLAB/NSF/AURA

2 Bennett (C/1969 Y1)

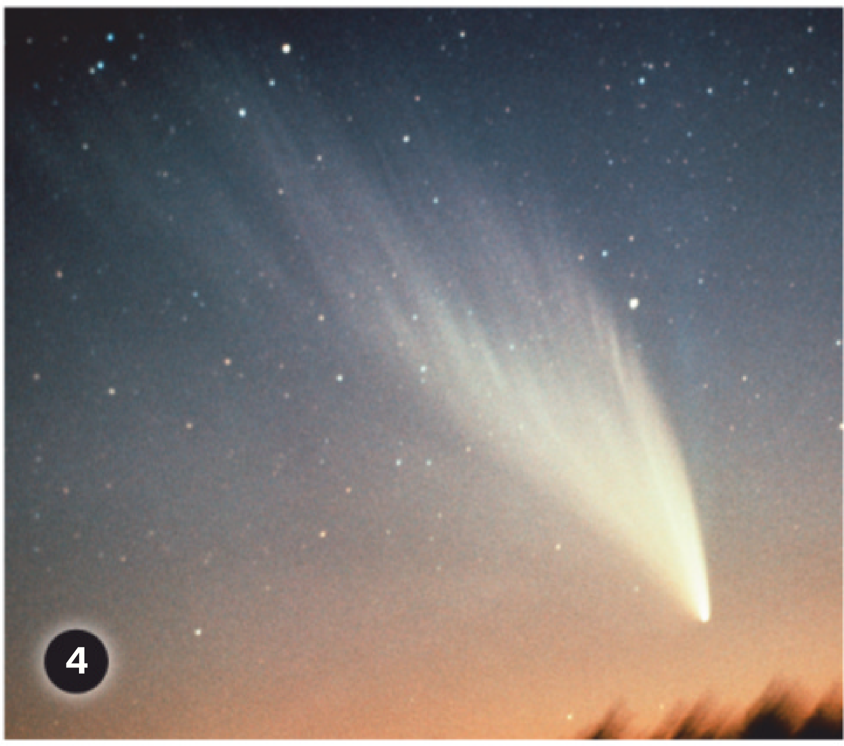
Bennett's ion tail featured a prominent kink, seen in this two-minute exposure taken April 4, 1970, with the 0.8-meter Schmidt telescope at Hamburg Observatory. Nine days later, the crew of Apollo 13 attempted to photograph Comet Bennett from deep space, but they were unsuccessful. BURLAGA ET AL. 1972; K. LUBECK, HAMBURG OBSERVATORY

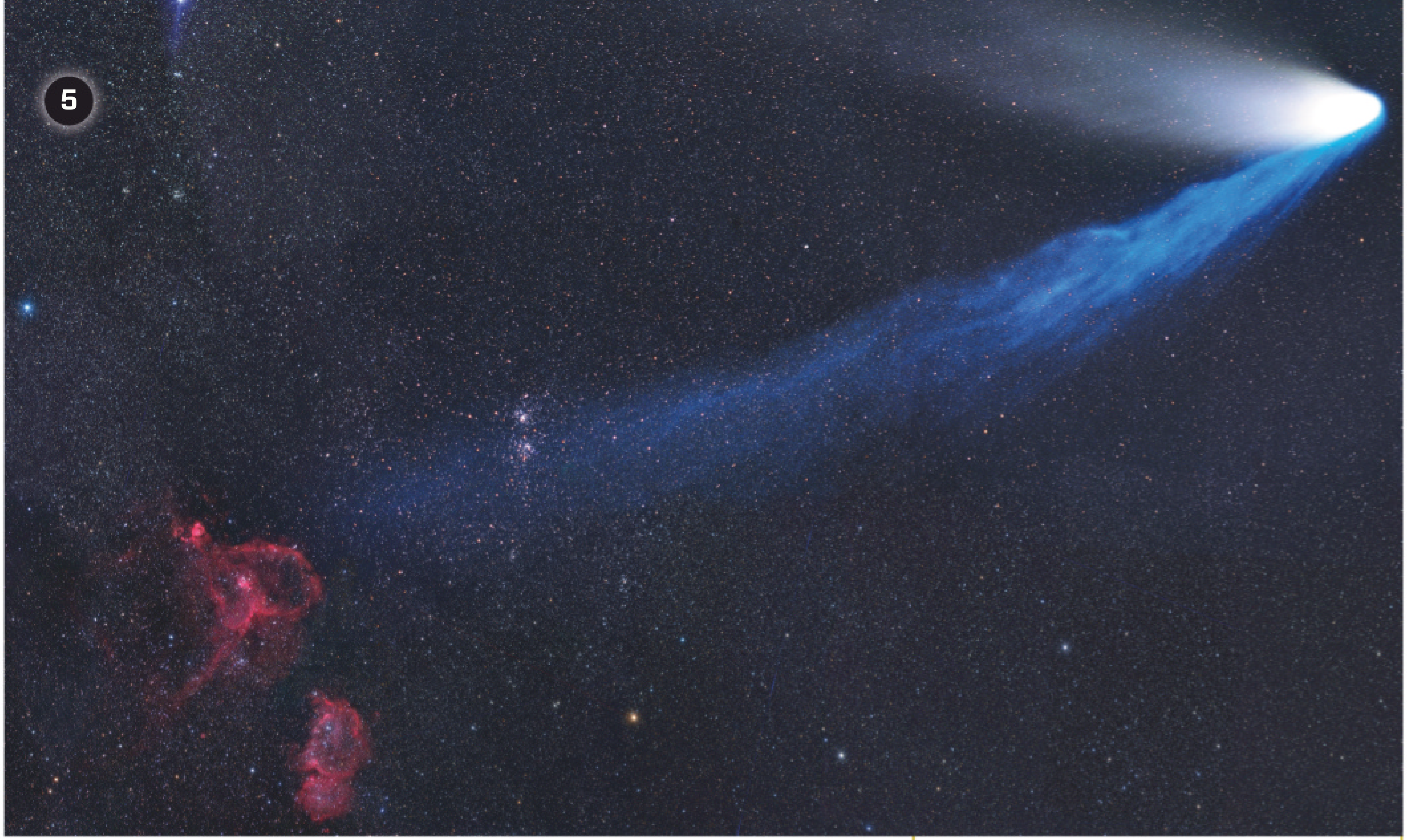
3 Kohoutek (C/1973 E1)

Comet Kohoutek may not have lived up to its billing as the "comet of the century," but this three-minute exposure on Palomar Observatory's 1.2-meter Schmidt telescope taken Jan. 12, 1974, captured its streaming tail in stunning detail. PALOMAR OBSERVATORY

4 West (C/1975 V1)

Burned by the letdown of Kohoutek, the media did not trumpet Comet West with much fanfare. But West put on a fine display and reached a peak apparent magnitude of –3, making it the brightest comet since Ikeya-Seki. J. LINDER/ESO





5 Hale-Bopp (C/1995 O1)

The magnificent Comet Hale-Bopp was already visible to the naked eye in May 1996, nearly a year before it reached perihelion. When it reappeared after swinging around the Sun, it remained visible unaided through nearly all of 1997. In this shot taken April 2, 1997, its blue ion tail is passing over the Heart and Soul nebulae (IC 1805 and IC 1848) at lower left and, just to the right, the Double Cluster in Perseus (NGC 869 and NGC 884). GERALD RHEMANN

6 Halley (1P)

Comet Halley's most recent apparition, in 1986, was its least-favorable on record, especially for Northern Hemisphere viewers. Still, it was a nearly-once-in-a-lifetime chance to see the most famous comet in history. This photo captures one such moment from Lake Havasu, Arizona, in March of that year. ALAN DYER

7 Levy (C/1990 K1)

Comet hunter David Levy is perhaps best known for his co-discovery of Shoemaker-Levy 9, which smashed into Jupiter in July 1994. But Comet Levy (C/1990 K1) put on a show closer to home, reaching magnitude 3.1 in August 1990. It was also the first comet observed by the Hubble Space Telescope. CHRIS SCHUR

8 Hyakutake (C/1996 B2)

As the world awaited the arrival of Hale-Bopp in early 1996, Comet Hyakutake, discovered Jan. 31, suddenly rose to prominence, temporarily stealing the spotlight with a colorful display. This five-minute exposure was taken as Hyakutake reached perihelion in April 1996. GERALD RHEMANN

— continued on page 54

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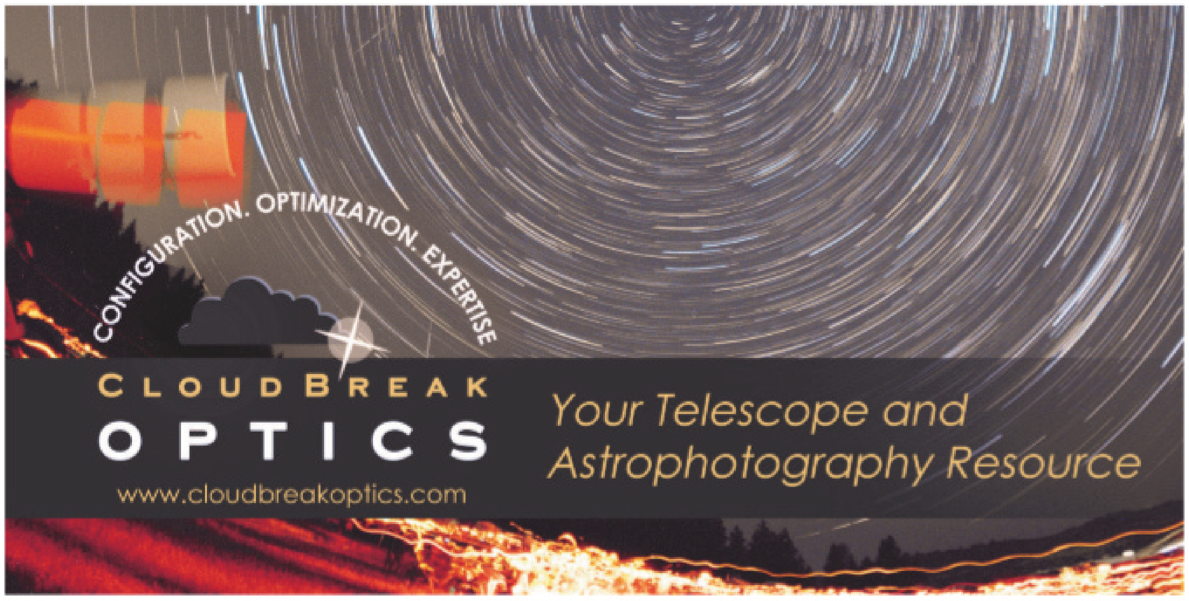

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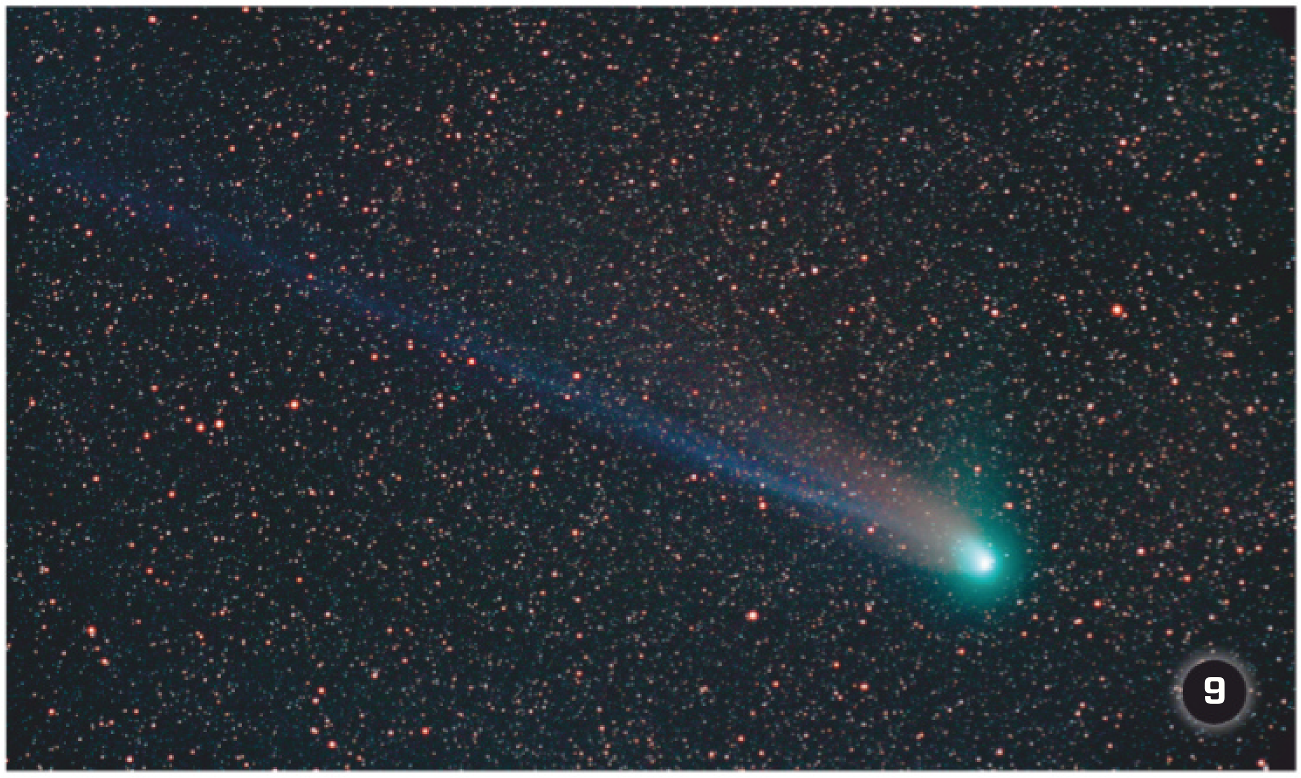
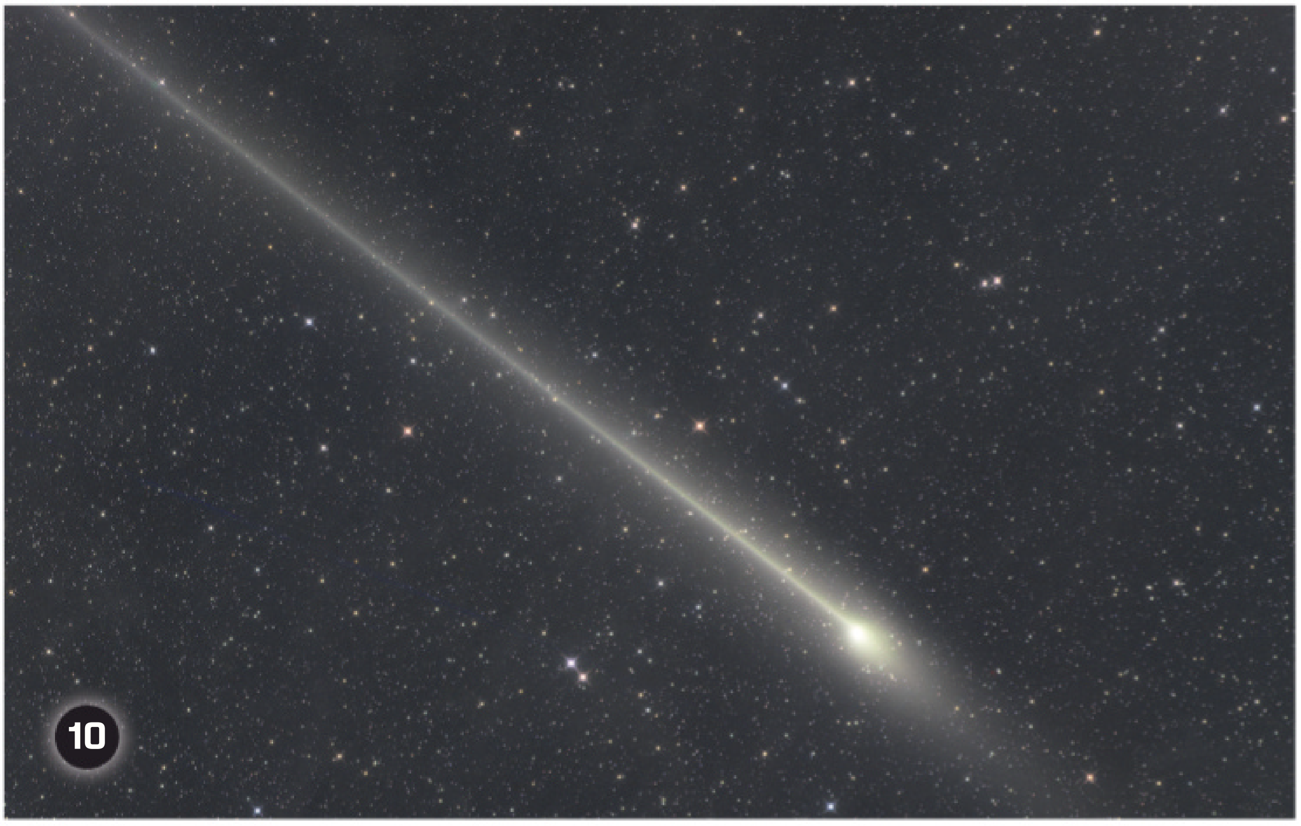
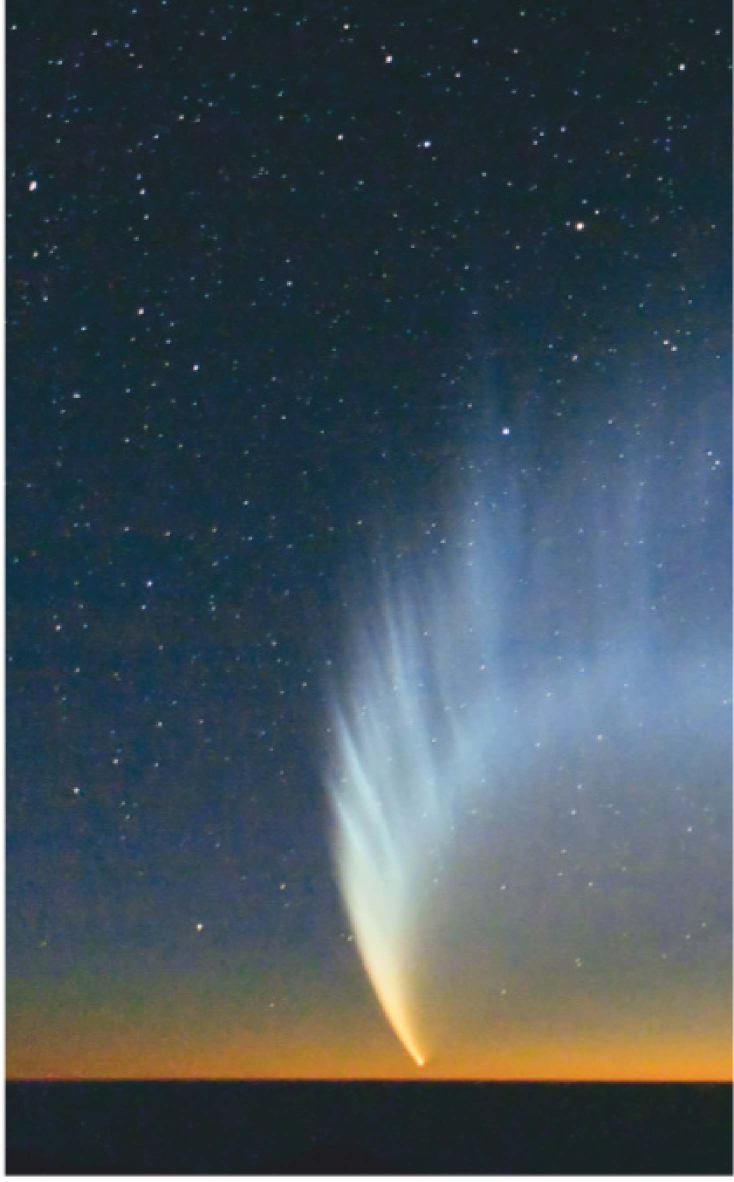
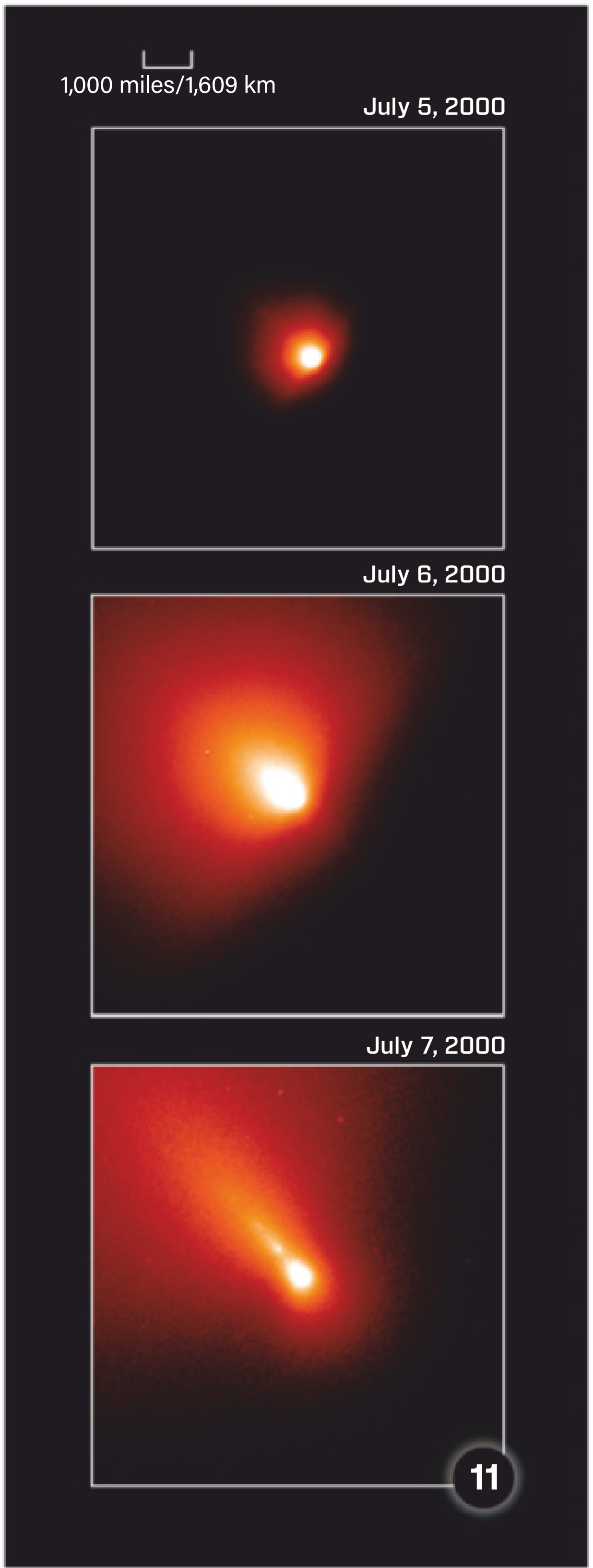
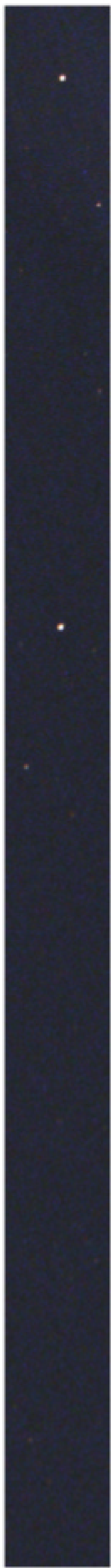










9 NEAT (C/2002 V1)

Comet NEAT revealed a couple of intriguing scientific implications. To many astronomers' surprise — and despite its apparent diminutive size — it survived its close encounter with the Sun. It even endured a solar storm in the form of a coronal mass ejection, a powerful cloud of charged particles ejected from the surface of the Sun. This plasma interacted with the tail, putting a kink in it. CHRIS SCHUR

10 PANSTARRS (C/2011 L4)

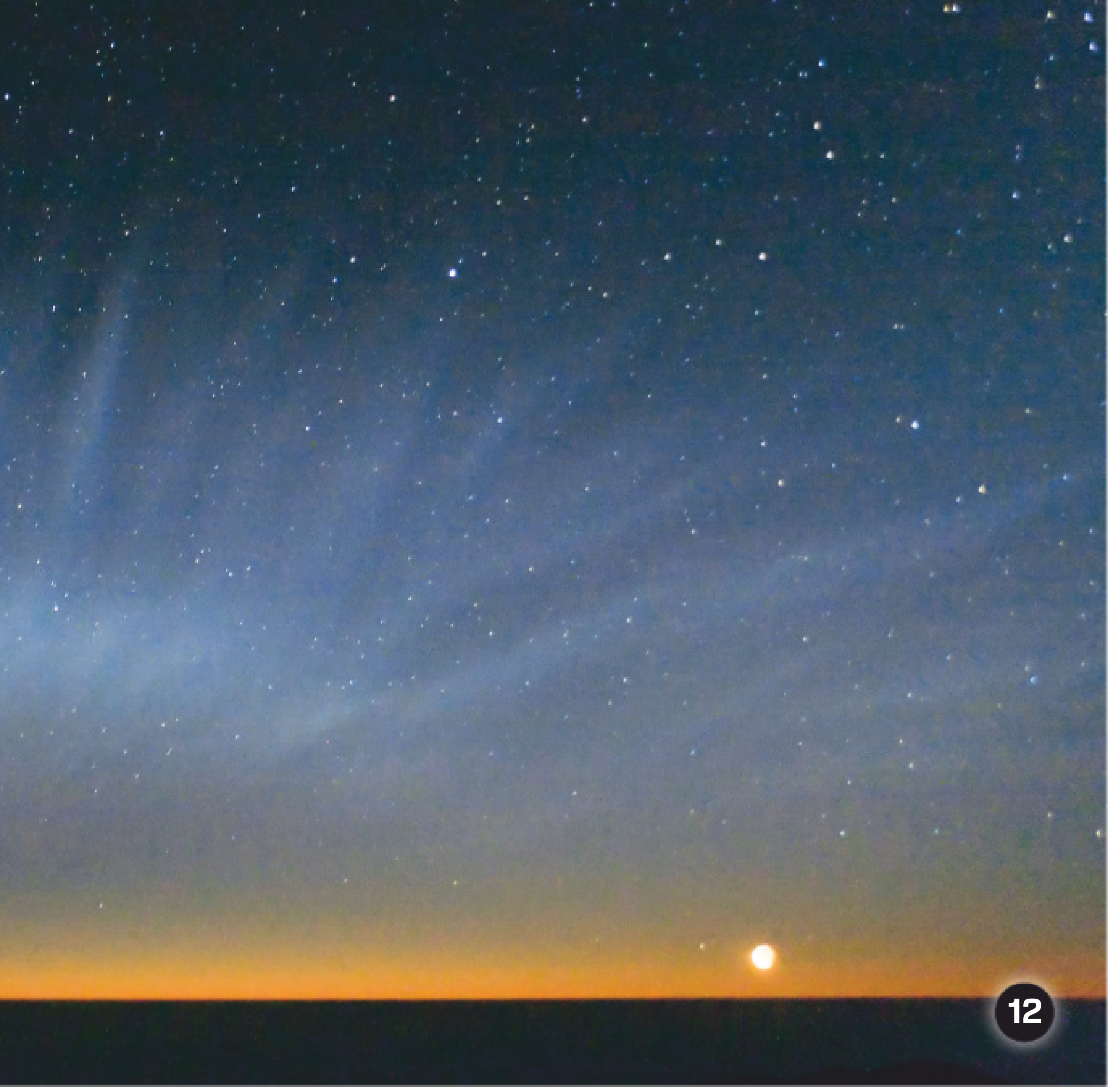
When this comet was discovered in June 2011 by the Pan-STARRS telescope on Haleakalā in Hawaii, it still lay between the orbits of Jupiter and Saturn. It finally became visible to the naked eye near perihelion in March 2013. Although it did not quite match initial brightness predictions, it featured a remarkably long anti-tail that spanned as much as 7°, visible in this May 22 image. GERALD RHEMANN

11 LINEAR (C/1999 S4)

Comet LINEAR was, overall, a bit of a disappointment, disintegrating before it reached perihelion in late July 2000. But before it fell apart, the Hubble Space Telescope managed to capture a dramatic outburst in early July, when the comet suddenly brightened by half in the span of four hours and, a day later, expelled a chunk of its crust behind it. These images offered scientists one of their most detailed glimpses to date of how a comet erupts and fragments. NASA, H. WEAVER AND P. FELDMAN (JOHNS HOPKINS UNIVERSITY), M. A'HEARN (UNIVERSITY OF MARYLAND), C. ARPIGNY (LIEGE UNIVERSITY), M. COMBI (UNIVERSITY OF MICHIGAN), M. FESTOU (OBSERVATOIRE MIDI-PYRENEES), AND G.-P. TOZZI (ARCETRI OBSERVATORY)

12 McNaught (C/2006 P1)

Comet McNaught proved a treat for Southern Hemisphere observers, featuring prominent striations in its spectacular dust tail. The beautiful structure was captured fanning out above the Pacific Ocean in this image taken from Paranal Observatory in Chile in January 2007. S. DEIRIES/ESO



13

ISON (C/2012 S1)

Like so many comets before it, ISON was heralded and hyped but ultimately turned out to be a dud — relatively speaking. It still proved an alluring photographic target, as this shot from Nov. 21, 2013, demonstrates. GERALD RHEMANN

14

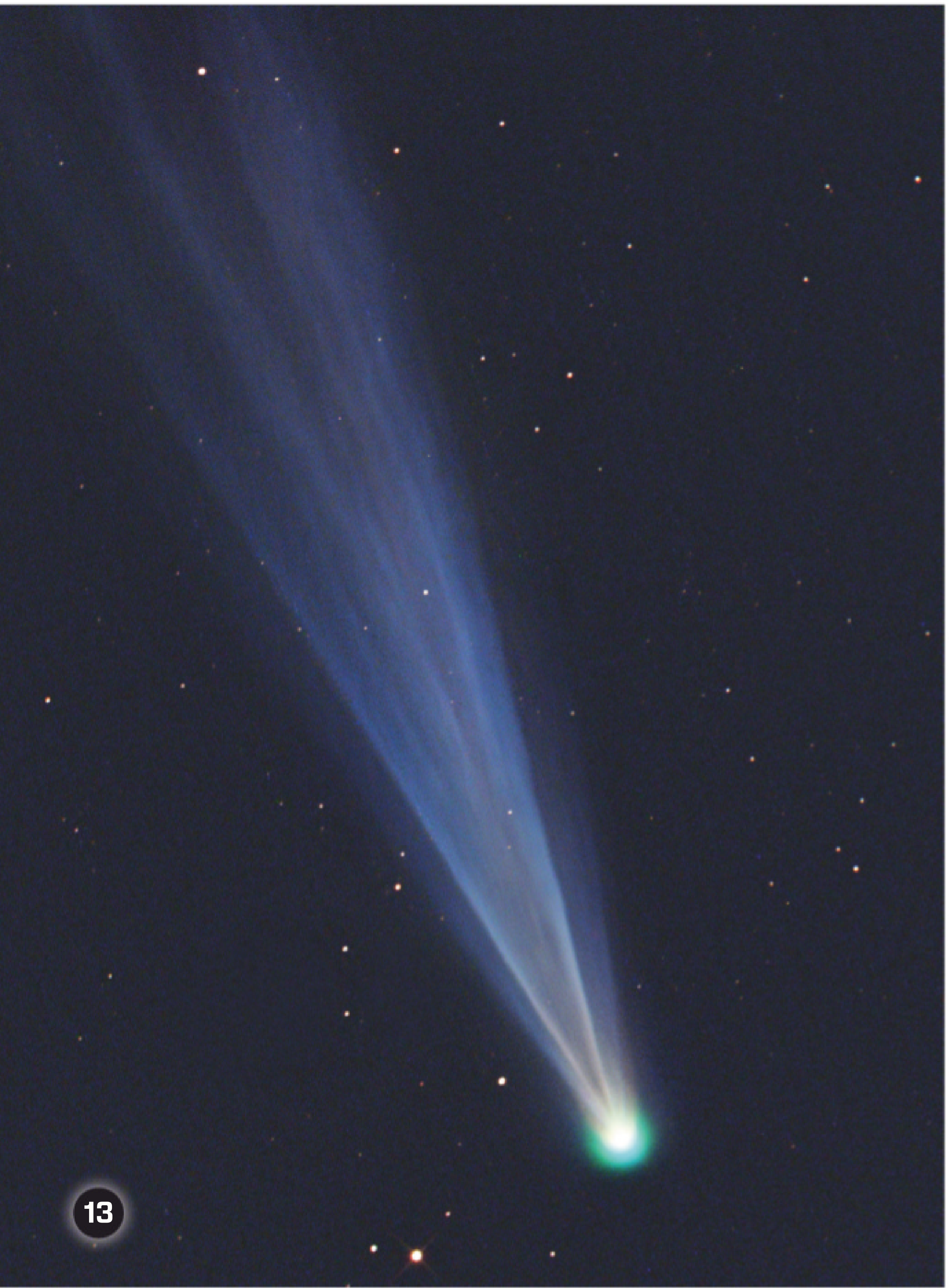
Holmes (17P)

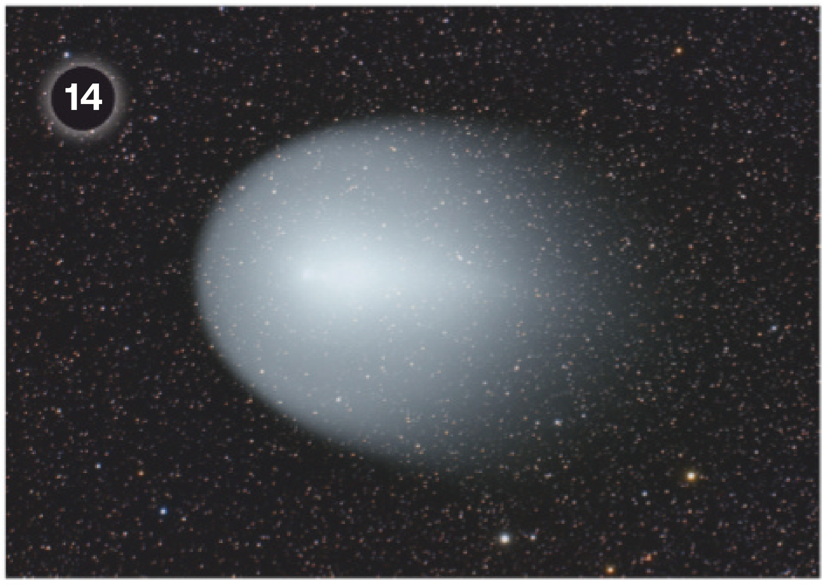
Comet Holmes was discovered by Edwin Holmes in 1892 and has a period of just under seven years. But it was lost for several decades between 1906 and 1964 as it was too faint. It gave its most dazzling performance in October 2007, when it suddenly underwent an outburst. This image was taken Dec. 3, after the coma had expanded to a volume greater than that of the Sun. CHRIS SCHUR

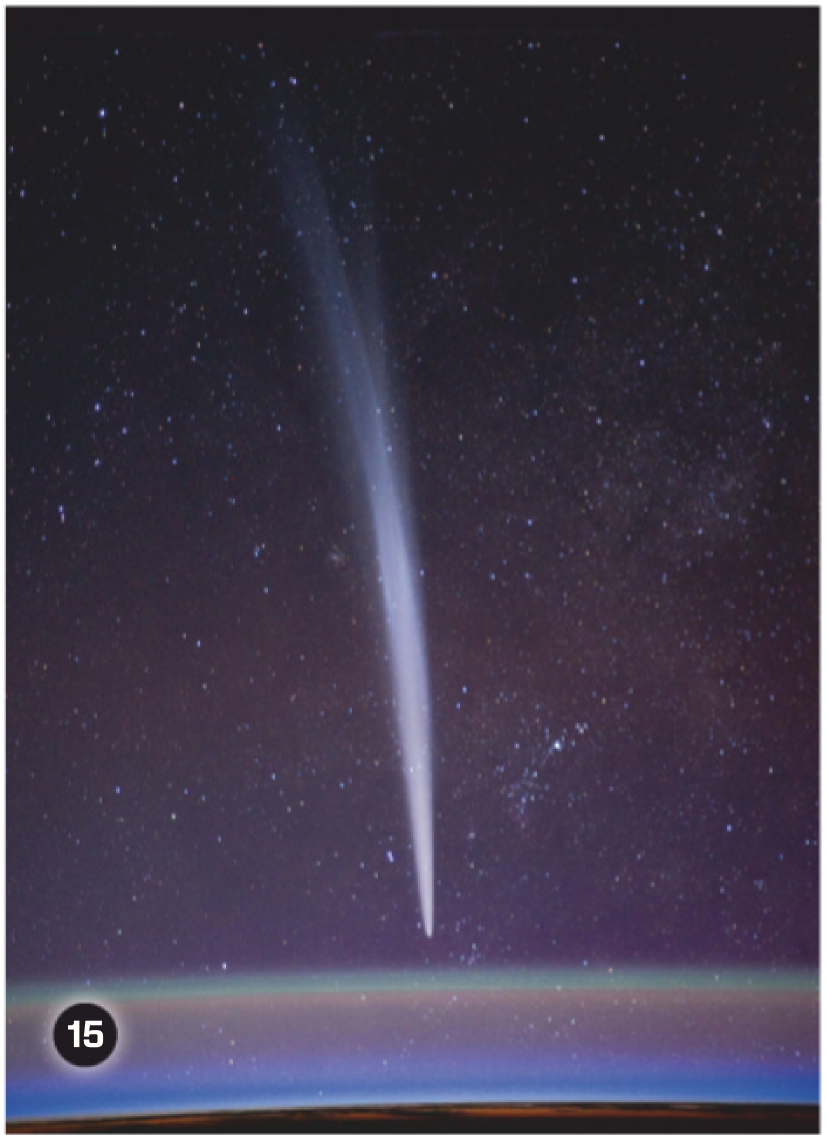
15

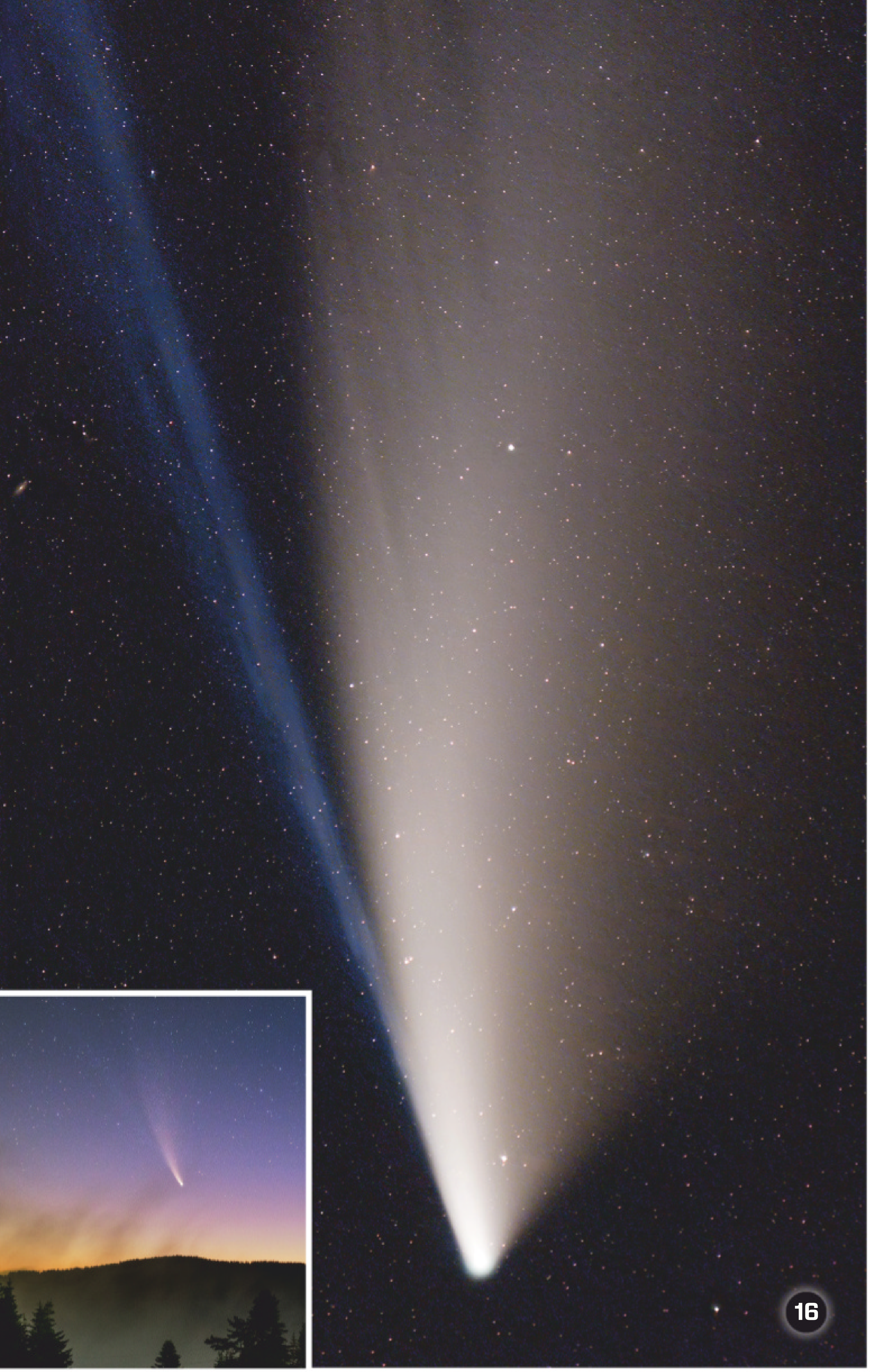
Lovejoy (C/2011 W3)

Comet Lovejoy was discovered in November 2011 and emerged from perihelion in mid-December, putting a glimmering celestial bow on a festive time of year. Here, it appears above the limb of Earth Dec. 22, 2011, as photographed from the International Space Station by the orbiting laboratory's then-commander Dan Burbank. NASA









16 NEOWISE (C/2020 F3)

Comet NEOWISE was discovered in late March 2020, just as the world was locking down due to the COVID-19 pandemic. When it peaked July 23, it was the brightest comet since McNaught. Millions around the world went outside to observe it — socially distanced but reveling together in the sight of a sublime cosmic phantom. While astronomers debate whether NEOWISE qualifies as a great comet, we can all agree on one thing: Hopefully, the next great comet will arrive amid more auspicious circumstances. ADAM BLOCK. INSET: TUNC TEZEL

***Mark Zastrow** is a senior editor of* Astronomy. *As a child, his first great comet was Hale-Bopp, but what he really remembers is the sight of grown men in a bank weeping the next day recalling its beauty.*

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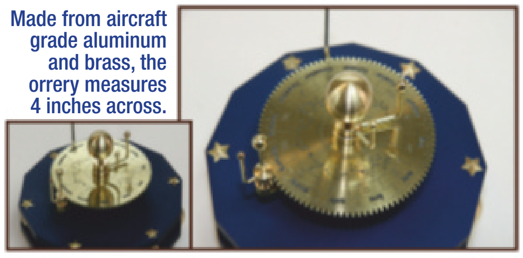

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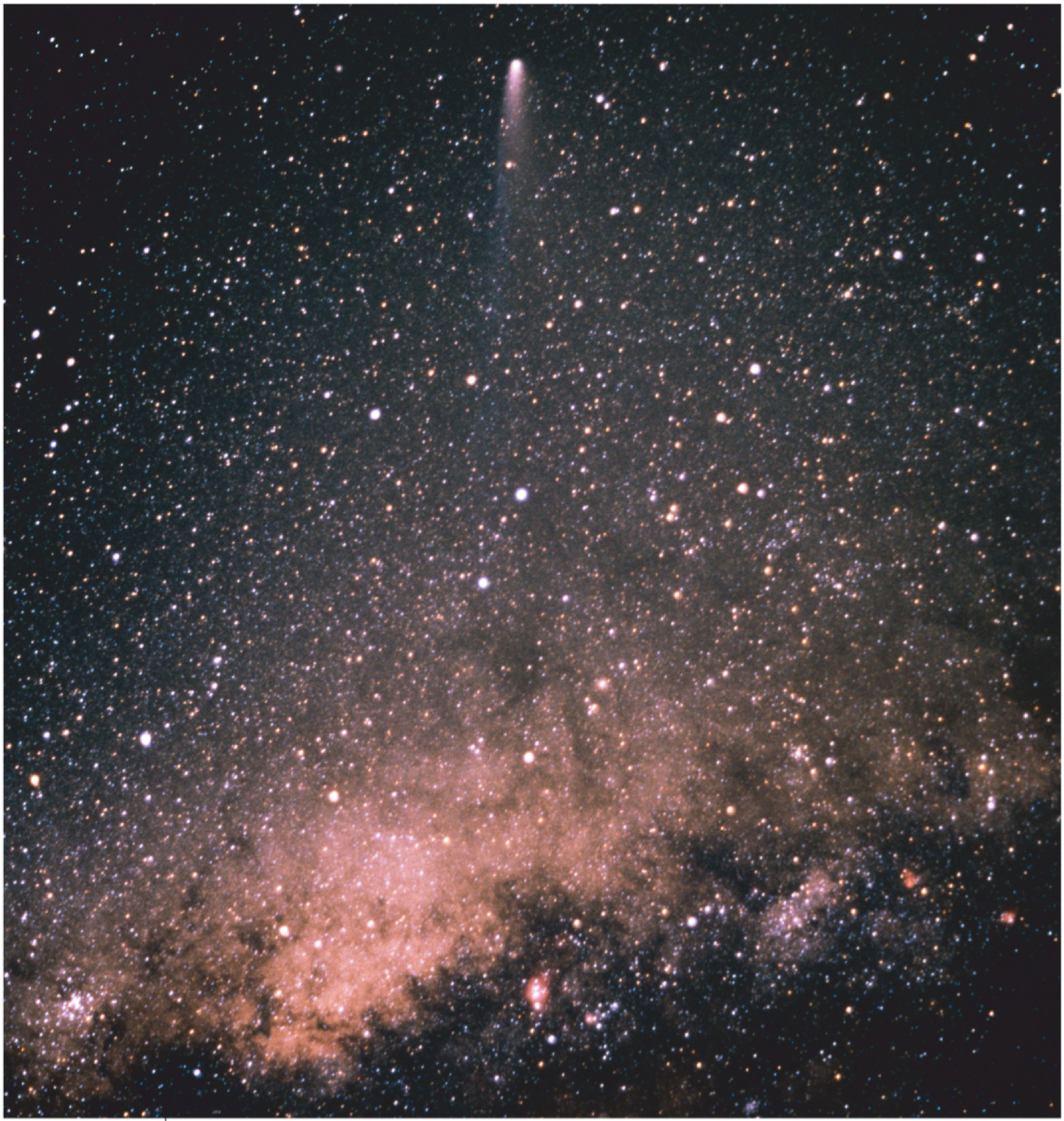

HALLEY PLIES THE MILKY WAY

For the past 37 years, Comet 1P/Halley has been edging its way ever deeper into the solar system. Now well beyond the orbit of Neptune, history's most famous comet will start its long journey back toward the Sun in late 2023. It will make its closest approach to both the Sun and Earth in July 2061, when it should reach 2nd magnitude among the dim background stars of the northern constellation Lynx. Observers will be in for a fine show — perhaps even better than during its 1986 appearance. This image shows Halley in March of that year against the backdrop of eastern Sagittarius, with the bright glow of the central Milky Way to its west. (North is to the right in this view.) ESO

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BY MARTIN GEORGE

March 2023

A match made in the heavens

Early March finds the two brightest planets embracing low in the western evening twilight. As magnitude –3.9 **Venus** continues to draw away from the Sun, it passes just 0.5° north of magnitude –2.1 **Jupiter** on March 2. The planets reside in Pisces the Fish and hang quite low in the sky, especially from more southerly latitudes, because the ecliptic — the apparent path of the Sun and planets across the sky — makes a shallow angle to the western horizon in late summer and early autumn.

By month's end, Venus will be in southern Aries the Ram, about two binocular fields to the lower left of the Pleiades star cluster (M45) in Taurus the Bull. The 6th-magnitude planet **Uranus** lies only 1.3° south of Venus on the 31st, making a fine sight through binoculars or a wide-field telescope. And needless to say, it's a great opportunity to find the normally elusive outer planet. Unfortunately, a scope does not add much to Venus. The inner planet's disk appears 14" across and three-quarters lit as April beckons.

Unlike Venus, Jupiter is now on its final approach to the Sun. A few weeks after its close conjunction with our sister world, the Sun's largest planet becomes lost in evening twilight. Jupiter's proximity to the Sun and low altitude also precludes the possibility of seeing much detail on the planet through a telescope.

Look higher in the evening sky and you should have little trouble picking out **Mars**. The Red Planet begins March among the horns of Taurus, not far from the magnitude 1.7 star Elnath (Beta [β] Tauri) that marks the northern horn's tip. Mars' slow eastward motion carries it 3.1° south of Elnath on the 9th and into the neighboring constellation Gemini the Twins on the 26th.

Although still a prominent object, Mars fades from magnitude 0.4 to 0.9 this month. As the planet dims, its disk appears to shrink, from 8" to 6" in diameter. This makes the ruddy world a less-appealing sight through a telescope than it was a few months ago.

March sees a welcome return of a favorite planet to the predawn sky. **Saturn** stands nearly 20° above the eastern horizon as twilight begins in late March. The ringed planet shines at magnitude 0.9 among the fainter background stars of Aquarius the Water-bearer. In contrast to its position in the western evening sky, the ecliptic shoots nearly straight up from the eastern horizon these March mornings.

A beautiful view of Saturn awaits anyone who points a telescope in its direction. The rings now tilt just 9° to our line of sight. (In two years, they will appear edge-on.) Although it's harder to see Cassini's Division in the rings when they have a lower tilt, I find it easier to view the planet's disk and some of its fainter moons. Of course, one moon is always prominent: 8th-magnitude Titan, the solar system's second-largest satellite.

Mercury stays pretty much out of sight all month. It passes on the far side of the Sun from our perspective, a configuration known as superior conjunction, March 17.

The starry sky

The constellation Puppis the Stern passes nearly overhead on March evenings. It is one of the three constellations that astronomers formed from the large, unwieldy constellation Argo the Ship, which Jason and the Argonauts supposedly used in their search for the Golden Fleece, and it contains a number of intriguing objects.

After astronomers divided the Ship, each of the constellations Puppis, Carina, and Vela retained their original Greek letters from Argo. Thus, all three have several "missing" letters. For example, Alpha (α) Argûs (Canopus) has become Alpha Carinae, but no Alpha star exists in Puppis or Vela.

Puppis' brightest star is the original Zeta (ζ) Argûs, so we now call it Zeta Puppis. I recently came across an 1874 letter in the newspaper *Australian Town and Country Journal* in which a reader mentioned Zeta Argûs because of its proximity to the direction of Comet Coggia, a prominent object that year. The writer described the comet's tail as 2.5° in length and extending "directly towards the bright star Zeta Argûs."

The star has long been known as Naos after a Greek word meaning ship. Indeed, it appears as such in Elijah Burritt's *Geography of the Heavens* (1856). This name did not become official until 2016, however, when the International Astronomical Union included it in its list of approved star names. In including the name Naos in his text, Burritt also referred to it as being part of the giant (and obscure) asterism known as the "Egyptian X" formed by Naos, Phact (Alpha Columbae), Betelgeuse, Procyon, and Sirius.

Naos shines at magnitude 2.2 and is easy to spot even under light-polluted skies. Its apparent magnitude belies its true nature, however. In terms of absolute brightness, Zeta Pup is one of the most brilliant stars known. It has an absolute magnitude of –6.2, which is the magnitude it would appear to have if seen from 10 parsecs (32.6 light-years) away. It therefore shines 11 magnitudes, or 25,000 times, brighter than the Sun.

The binocular field in the vicinity of Naos is very attractive. It includes NGC 2451 (which I explored in a previous article and appears like, but is not actually, an open star cluster), NGC 2477 (Caldwell 71), and NGC 2546. I'll take a closer look at the latter two another time.

STAR DOME

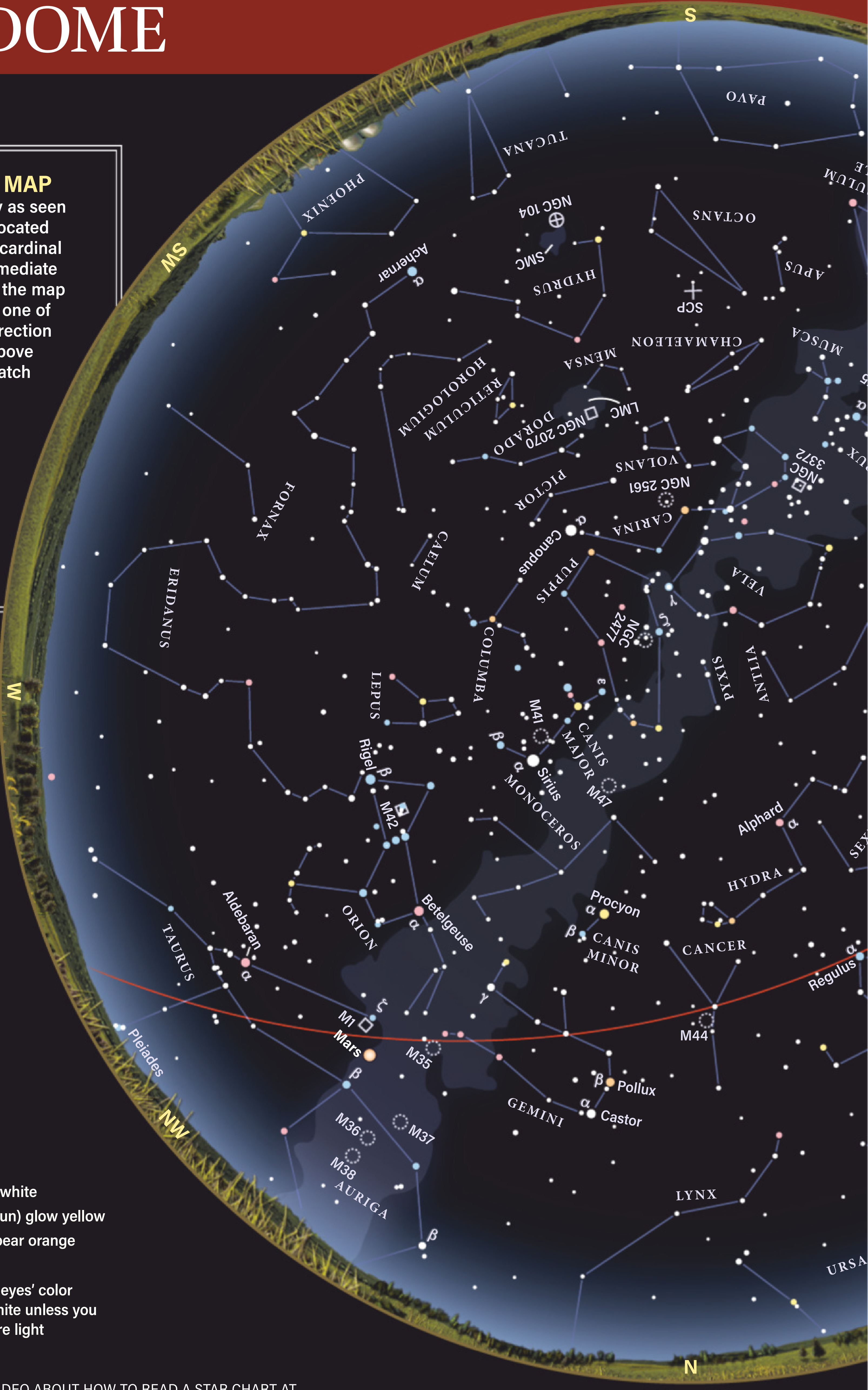
HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. March 1
9 P.M. March 15
8 P.M. March 31

Planets are shown at midmonth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ANTLIA
M41
CANIS MAJOR
Rigel
β
Sirius
MONOCEROS
M47
M42
Alphard
HYDRA
Procyon
CANIS MINOR
Betelgeuse
ORION
Aldebaran
TAURUS
CANCER
Regulus
M44
M1
Mars
M35
Pleiades
Pollux
Castor
GEMINI
M36
M37
M38
AURIGA
LYNX
URSA

MAP SYMBOLS

- ◌ Open cluster
- ⊕ Globular cluster
- ☐ Diffuse nebula
- ⌖ Planetary nebula
- ⬭ Galaxy

STAR MAGNITUDES

● Sirius

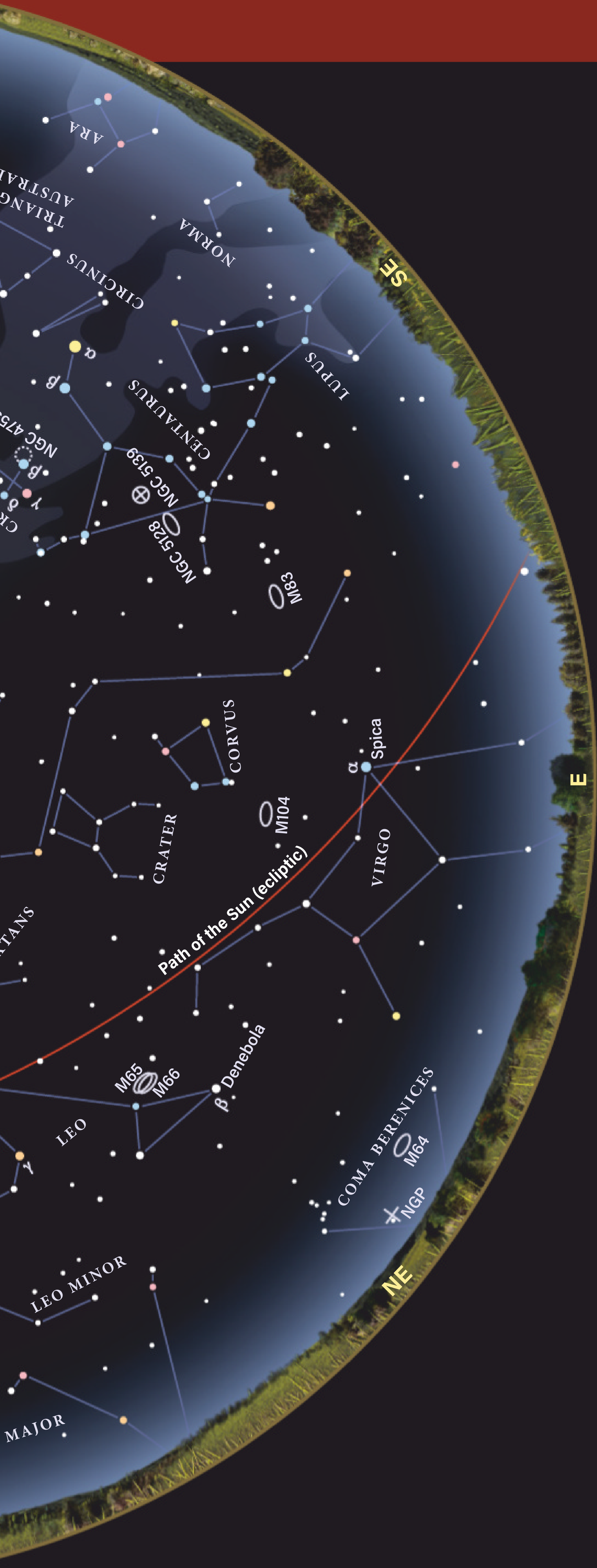
●	0.0	•	3.0
●	1.0	•	4.0
•	2.0	·	5.0

STAR COLORS

A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**


ARA
NORMA
CIRCINUS
SE
α
β
LUPUS
CENTAURUS
NGC 5139
NGC 5128
M83
CORVUS
α
Spica
E
M104
CRATER
VIRGO
Path of the Sun (ecliptic)
β
Denebola
M65
M66
LEO
COMA BERENICES
M64
NGP
NE
LEO MINOR
MAJOR

MARCH 2023

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

2 Venus passes 0.5° north of Jupiter, 11h UT

3 The Moon is at apogee (405,889 kilometers from Earth), 18h00m UT

7 Full Moon occurs at 12h40m UT

15 Last Quarter Moon occurs at 2h08m UT

16 Neptune is in conjunction with the Sun, 0h UT

17 Mercury is in superior conjunction, 11h UT

19 The Moon passes 4° south of Saturn, 15h UT

The Moon is at perigee (362,696 kilometers from Earth), 15h12m UT

20 March equinox occurs at 21h24m UT

21 Dwarf planet Ceres is at opposition, 8h UT

New Moon occurs at 17h23m UT

22 The Moon passes 0.5° south of Jupiter, 20h UT

24 The Moon passes 0.1° south of Venus, 10h UT

25 The Moon passes 1.5° north of Uranus, 1h UT

28 The Moon passes 2° north of Mars, 13h UT

Mercury passes 1.5° north of Jupiter, 15h UT

29 First Quarter Moon occurs at 2h32m UT

31 Venus passes 1.3° north of Uranus, 6h UT

The Moon is at apogee (404,919 kilometers from Earth), 11h17m UT

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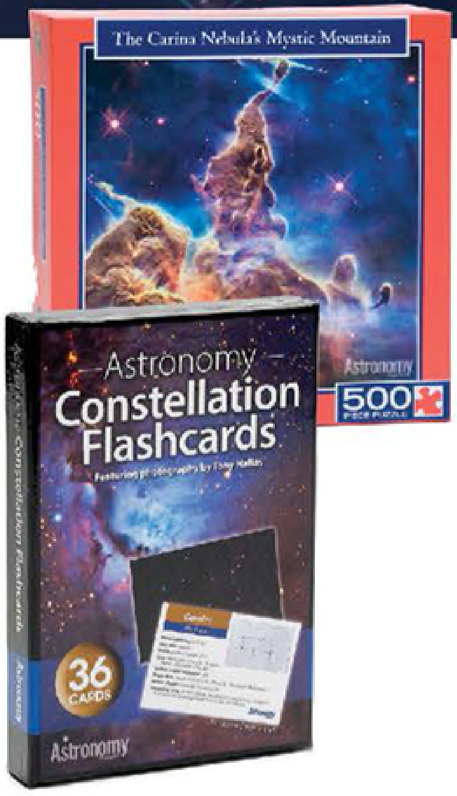
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GALILEOSCOPE

The Milky Way from above
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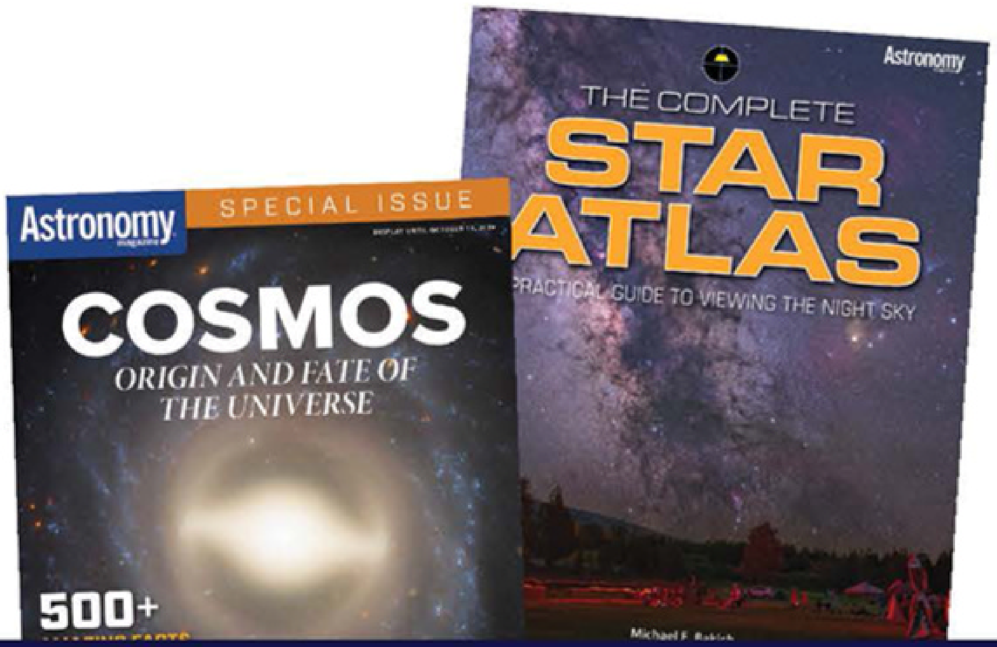
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